HIGH VOLUME FLYASH CONCRETE USAGE

For SkyTrain Stations

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Executive Summary

The GVRD Air 2000 Program commissioned Fast + Epp Structural Engineers, working in conjunction with Levelton Engineers Ltd. and Busby + Associates Architects to investigate the implications of increasing the fly ash volume to a 40-60% content level in the concrete works of the Brentwood and Gilmore SkyTrain stations.

This report reviews material quality issues of fly ash from local suppliers, the effects of fly ash in concrete, and local industry acceptance of increased fly ash usage. These are particularly reviewed in light of RTPO=s primary goals of construction value and the achievement of the 100-year design life.

Fly ash is a by-product obtained from the dust collectors of coal-fired power plants. It=s use in concrete is not new. However, many sectors of the building and research industry are 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 approximately 7% of the total world C02 emission. Increased fly ash usage would support Canada=s commitment to reduce greenhouse gas emissions. It not only reduces the amount of cement produced but also results in utilization of an otherwise unwanted byproduct.

The quality of local fly ash is excellent: possibly the best in the world. Fly ash=s effects on concrete are also largely positive. Fly ash generally increases durability, decreases permeability, greatly improves sulfate resistance and allows lower water contents in the mix. It also improves the workability of the wet mix and improves the color of the final product, producing a warmer tone.

It has few associated concerns, which are addressed in detail but are not seen as reasons to avoid the product. Fly ash concrete gains strength slower than plain cement concrete. This aspect may cause concerns or additional costs considering the fast-track nature of the Sky Train project.

Proposed modifications to the standard station specifications have been included to allow fly ash usage in station elements immediately with a minimum of effort.

A tendering strategy has been proposed that would minimize any additional costs and specifically quantify those that may arise due to increased fly ash volumes.

Many agencies, including CALTRANS are on the verge of mandating minimum levels of fly ash replacement. For the local construction industry, the question is not, AWill fly ash volumes increase?≅ but, AWhen will they increase?≅ As a result of our review of the available technical literature and survey of the industry, we recommend the RTPO take the lead in this process by mandating minimum levels of fly ash in station construction.

1.0 Introduction

1.1_ 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 SkyTrain station components.

The stations considered are Brentwood and Gilmore in Burnaby. The review also considers the possibility of using HVFA in the precast, prestressed station platform beams. These beams will be required at eight stations including Brentwood and Gilmore. We understand that, for economy of scale reasons, the Rapid Transit Project Office (RTPO) will tender the platform beams for all stations in one package, therefore the scope of this report effectively applies to eight stations in total.

The report team is lead by station structural engineers Fast + Epp, supported by Levelton Engineering Ltd., who have provided their material engineering expertise. Also included on the team are the station architects, Busby + Associates Architects for their input regarding aesthetic concerns.

1.2 Background

1.2.1. Materials

Fly ash is a fine, light-brown powdery waste product obtained from the dust control equipment of coal-fired power plants. A large volume of this waste product is produced every year[1]. Though some secondary uses for it are found, much of it finds its way to land fills.

For over 60 years, fly ash has been employed in Portland Cement concrete as a supplementary cementing material[2]. ASTM divides cementing fly ash into two main types: Class F which is derived from burning anthracite or bituminous coal and Class C, a by-product of burning lignite or sub-bituminous coal. Type C fly ash is further subdivided depending on calcium content; intermediate levels are designated CI and high levels are designated CH. In B.C., fly ash comes from two sources, namely, Sundance, Alberta and Centralia, Washington. Sundance is class F and Centralia Class CI (a subdivision of the larger Class C category), and both are of good quality.

An in-depth review of the chemistry of fly ash in concrete goes beyond the scope of this report. In short, however, fly ash reacts with calcium hydroxide, a by-product of the hydration of Portland Cement. Fly ash transforms a relatively inert hydration cement by-product into useful structural matrix material thereby primarily adding beneficial properties to concrete. These properties and their effects on concrete will be discussed later in the report.

Portland Cement production increases yearly and, after aluminum and steel, is the third most energy intensive material production process. Production of cement not only consumes a large amount of energy but also contributes a significant amount of greenhouse gases to the atmosphere. It is estimated that worldwide production of cement accounts for almost 7% of the total world C02 production. In support of Canada=s commitment to reduce greenhouse gas emissions, the GVRD, Canmet, Industry Canada, Environment Canada, PWSC and other government agencies are investigating the increased use of fly ash in concrete.

[1] 400 million tonnes of total coal ash were produced worldwide in 1989. Malhotra, Making Concrete Greener with Fly Ash, Concrete International, May 1989
[2] Dean Golden, E.P.R.I., from CANMET/ACI International Symposium on Concrete Technology for Sustainable Development

The concern for greenhouse gases drives the desire for increased fly ash percentages in concrete but also should affect member design. Greenhouse gas emissions will be reduced by optimal designs that minimize total tonnage of concrete and steel usage.

Also of interest is the global nature of the problem. Cement is a global commodity. Should local plants experience a reduced demand for their product as a result of fly ash replacement, they will most likely find markets elsewhere, whether that be in the U.S. or South America. Given this economic reality, Vancouver=s air will not necessarily be improved by the local use of fly ash, however we can take the lead and make a step here that will reduce the global problem.

1.2.2 Usage

Typical construction practice replaces about 15% of cement with fly ash in applications that permit it. Suppliers generally promote this replacement, as it lowers their material cost. Contractors also support the use of fly ash, as the fine particles act like ball bearings and increase the workability of the mix[3]. Engineers, in the past, however have been reluctant to endorse increased use of fly ash. This reluctance primarily results from early codes restricting its use in concrete. These codes were based on earlier generations of fly ash which were very coarse and had very high carbon contents[4]. The reluctance also was likely due to the lack of literature available and the suspicion that anything that lowers the supplier=s cost must have negative product consequences and therefore should be resisted by the engineer.

Current construction codes have removed the restriction based on the increased quality of the product now available from coal plants. This factor, in conjunction with the desire to produce more environmentally friendly concrete has produced fairly extensive research on the use of High Volume Fly Ash (HVFA) concrete. The optimum HVFA ratio (based on mix cost per Mpa of compressive strength[5]) replaces 50% to 60% of cement in a typical mix. These mixes currently have laboratory tests and some field application history supporting them.

For the purposes of this review, HVFA concrete will be defined as a mix that contains at least 50% replacement of cement by fly ash or, in other words, a mix which contains at least as much fly ash as cement.

1.3 Goals

RTPO, apart from meeting Canadian Environmental Assessment Agency (CEAA) commitments, has no specific mandate to assess global implications of material use. Thus, potential HVFA usage should be based primarily on sound engineering principles with reasonable amounts of experience and technical support behind them. We therefore have investigated the literature and current field experience in order to assess whether HVFA can be shown to be as practical and economical as Atraditional≅ concrete.

We understand the Rapid Transit Project Office reviews new materials and construction methods in light of the following criteria:

X Durability Does it meet the 100 year design life requirement?
X Cost Efficiency Does it enable provision of facilities within their fixed budget?
X Schedule Does it enable elements to fit within the greater project schedule without causing costly delay to downstream items and/or contractors?
X Aesthetics Does it comply with aesthetic guidelines set for the project?
X BC Content Does it meet the BC content guidelines for the project?

[3] Other fly ash characteristics also improve rheology (workability) such as its dispersing action. P.K.Mehta, Role of Flyash in Sustainable Development.
[4] Ibid.P24
[5] Wilbert Langley, AField Experience with High Volume Fly Ash Concrete Utilizing Low Calcium Fly Ash.

Using these five criteria, we have evaluated HVFA versus Atraditional≅ Portland Cement concrete as specified in the Standard Station Specifications. We recognize that RTPO has not strictly quantified the 100 year design life but rather defined a durable structure by stating prescriptive limits on concrete mix proportions and cover requirements etc.

2.0 Materials

2.1 Local Fly Ash

2.1.1. Ownership

Because BC has no coal burning plants, it does not produce fly ash. Lafarge obtains their fly ash from Alberta=s Sundance Transalta coal-fired power plant. Tilbury Cement obtains their fly ash from Centralia in Washington. Both are good sources. Both companies have arrangements with their sources so that the type of fly ash is generally linked to the cement supplier. Fly ash should be viewed as an imported raw material to which BC companies add value.

2.1.2. Quality

Like all materials used in the production of concrete, fly ash must meet the requirements of construction specifications. These should reference ASTM 618 AFly Ash and Raw or Calcined Natural Pozzolans for Use as a Mineral Admixture in Portland Cement Concrete,≅ and CAN/CSA A23.5 ASupplementary Cementing Materials.≅ The latter is largely based on the former.

Calcium content in fly ash governs its ability to provide high early strength, which aids in accommodating construction sequencing. The higher calcium contents of Type C fly ash are able to provide primary cementing action as opposed to the secondary cementing action provided by type F. Local fly ashes are type CI from Centralia and F from Sundance. Ash from Centralia has calcium contents on the lower limit of the C scale (CI) thus providing slightly greater early strength than the Sundance ash.

Overly high carbon contents in fly ash make air entertainment difficult as carbon absorbs air-entraining agents. Loss On Ignition (LOI) is a measure of unburned carbon remaining in the fly ash. It is desirable to maintain the lowest level of LOI possible, especially for air entrained concrete. A low LOI is also desirable to prevent discoloration of the concrete. LOI for class F fly ash was previously limited to 12 percent but has been lowered to 6 percent by ASTM C618-83. The market will not accept more than 4%. West coast fly ashes do not struggle with high carbon contents and typically have carbon contents in the order of 1%.

Fineness of fly ash particles is a critical factor determining their pozzolanic ability. Fly ash mineralogy and particle size rather than chemistry determine most of the fly ash effectiveness[6]. Particles larger than 45 microns are essentially inert. Particles under 10 microns assist the most with early strength and particles between 10 and 45 microns are what cause the long term strength gain associated with fly ash. All the size characteristics are readily controlled, tested and monitored. ASTM 618 places an upper limit on coarseness of fly ash at 34 percent retained on the #325 (44-micron) sieve.

As a more performance oriented measure, ASTM 618 also has a Strength Activity Index. Strength activity with cement is a measure of the reactivity of fly ash in a mortar mix where 20 percent by weight of cement is replaced with like weight of fly ash.

Thus the fly ash properties of interest to the structural performance can be specified, readily measured and monitored.

[6] Ibid.P14

2.1.3. Variability

The two elements of most concern in terms of fly ash variability are carbon content and fineness. Both carbon content and fineness have not typically fluctuated in product supplied by local producers. Data from Centralia obtained through Pozzolanic International indicate that the percentage of total weight of particles larger than 44 microns has varied minimally. The total amount of these particles in any given sample ranged between 7% and 11% over a sample period of three months. Likewise, the percentage of total weight of carbon has ranged between 0.23% and 0.53% over the same sample period. These are both well below ASTM specified levels.

Some concerns have been raised regarding the requirement of coal plants to reduce NO_x emissions. To achieve these reductions, they may reduce burning temperatures below optimal thereby increasing the carbon content. In order to retain the demand for this waste product that they would otherwise need to discard, coal plants have added additional processes. Centralia has recently gone to a process where they classify their product into two categories. The Aclassified≅ ash has fineness gradations within certain parameters and carbon contents below specified limits. Unclassified fly ash may be a good product but its properties are not known as accurately.

In summary, local fly ash is a premium world class product with excellent material properties. Nevertheless, for quality assurance purposes critical properties should be measured and documented for RTPO projects.

2.2 HVFA Concrete

2.2.1 Typical Mixes

The following table summarizes typical mix designs and hypothetical RTPO mix designs for cast-in-place concrete elements. Note that prestressed, precast elements will require higher early strengths using enhanced curing methods.

TABLE 1

Component	**Units**	**Cement Only Mix (0%)**	**Canmet Mix* (58%)**	**LiuCentre** (50%)**	**Proposed RTPO Normal Mix (30%)**	**Proposed RTPO HVFA Mix (50%)**
Cement	kg/m3	350	156	195	245	200
Fly Ash	kg/m3	0	215	195	105	200
Total Cementitious	kg/m3	350	371	390	350	400
Water	l/m3	165	120	130	145	130
water /cementitious ratio		.47	.32	.33	.41	.33
fly ash / cementitious ratio		0	.58	.50	.30	.50
24 hour strength	mPa	22	8+/-2	9.7	15	8
4 day strength	mPa	30	20 +/-4	18.7	24	18
28 day strength	mPa	39	35+/- 5	32.2	35	35
56 day strength	mPa	43	39+/- 5	37.0	38	40

Superplasticizers and other admixtures may be used in the above mixes but are not shown in the table.

*CANMET is a division of National Resource Canada with a mandate to study properties of HVFA. The CANMET mix shown below exemplifies typical proportions on which their research has been based.

**The Liu Center is a recently completed project at the University of British Columbia that utilized HVFA concrete.

The RTPO mixes reflect mixes that meet the proposed requirements of RTP station specifications at two different fly ash replacement levels.
Note that all strengths are estimated (not guaranteed) based on normal cement and moist curing. Increased heat during curing as well as use of high early, finely ground cement would increase early strengths.

2.2.2. Durability

Fly ash increases concrete durability by two primary methods. The increased hydration from the fly ash with cement reaction creates a denser matrix and one that is much more impermeable. When water is prevented from entering the concrete structure, durability increases.

The second means by which HVFA increases durability is by allowing an optimally low level of mixing water in the wet mix. The ball bearing effect of the fly ash increases the flowability and allows w/c ratios of 0.3 and less. With this level of water in the mix, the concrete can form a dense well-sealed matrix. Permeability and durability primarily depend on the amount of mixing water. Fly ash mixes allow this water to be reduced.

2.2.3. Strength

HVFA can reach the same or greater design strength as normal concrete. HVFA strengths of 60 to 70 mPa are not uncommon, thus the nominal 35 mPa design strength for cast-in-place station components and 50 mPa for precast will be easily achievable.

The only strength issue will be the period of time at which the strength is measured for the purposes of the contract. HVFA concrete develops strength more slowly than a traditional cement mix. For the most latitude, HVFA would Aprefer≅ a 56-day strength measurement. The day at which strength is measured is arbitrary and the current CSA A23.1 allows for flexibility from the standard 28 day time frame.

2.2.4. Material Properties

For specimen tested at equivalent compressive strength, HVFA concrete exhibited marginally reduced material properties such as splitting strength, flexural strength and modulus of elasticity in comparison to cement only specimens[7]. The increased compressive strength of HVFA concrete over the long term would more than offset the slight reduction noticed at equivalent strengths. If tensile strength or modulus of elasticity at an early age are critical to designers, then they should consider these slightly decreased material properties.

2.2.5. Aesthetics

HVFA concrete reflects a light brown hue that many find preferable to the gray tone of plain cement concrete. Our team partner, Busby + Associates Architects have included their generally favorable opinion on the appearance of HVFA in the appendix of this report.

[7] Wilbert Langley, AField Experience with High Volume Fly Ash Concrete Utilizing Low Calcium Fly Ash.

2.3 Material Summary

2.3.1. Benefits

Type F fly ash concrete effectively moderates heat gain during concrete curing and is therefore considered an ideal replacement for cement in mass concrete, and high strength mixes. For the same reason, Type F is the solution to a wide range of summer concreting problems. It also provides sulfide and sulfate resistance equal or superior to Type V cement. Type F is often recommended for use where concrete may be exposed to sulfate ions in soil and ground water.

In addition to extensive work at CANMET, results from field tests have shown that high volume fly ash concrete has excellent durability characteristics - specifically reduced porosity/permeability and increased resistance to chloride ion penetration.

The literature contains much information on these benefits. In summary the benefits of HVFA concrete are 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

2.3.2. Concerns

There are a few concerns relating to HVFA. While not particularly applicable to station structures, they should not be overlooked.

.1 Scaling

Scaling is the breaking away of a hardened concrete surface, usually to a depth of 2 to 4 mm. The ASTM standard test method for this is C672-92. It requires repeated freezing and thawing of flat concrete plates immersed in salt water. After 50 cycles the specimens are rated based on their surface appearance. A 0 rating indicates no scaling and 5 indicates severe scaling. HVFA generally scores a 5. The test is severe and the magnitude of the poor performance has not been duplicated in the field. A Halifax test section of heavily trafficked sidewalk in a severe de-icing environment is performing adequately after six years (though not exceptionally).

The seeming paradox of HVFA scaling is that while fly ash produces more durable resistive concrete, its surface is less resistant to freeze thawing. While the mechanism behind this feature is not completely understood it is <u>not</u> indicative of an overall surface weakness: fly ash concrete surfaces perform well in abrasion tests. It is likely a moisture-related problem due to the smaller pores at the surface retaining more moisture.

HVFA specimen have been tested in severe marine environments for a number of years at Treat Island, and those with low water cementitious ratios are performing well. Mike Thomas of the University of Toronto has just completed research on hundreds of fly ash concrete installations, including some with HVFA, in the northeastern US and Ontario areas. He has concluded that there is no correlation between the ASTM C672 test results and the field performance of those concretes. There is currently no published documentation on

this work yet.
In the Lower Mainland, scaling has not been a concern for any concrete, thus this slight inherent weakness should not be considered a primary concern.

.2 Finishing

There are few steel trowelled surfaces at Brentwood and Gilmore stations. Almost all floor surfaces are covered by grout and finished with tile. However, 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.

.3 Cold Weather

Because of the reduced heat of hydration, cold weather concreting (below 5$^{\forall}$C) does not lend itself to large replacement volumes of fly ash. This is particularly true when considering thin members. Hoarding and heating would assist in curing of thin elements but would not aid in the goal of reducing emissions.

.4 Emissions

As fly ash is a waste product, the U.S. Environmental Protection Agency has reviewed possible health threats resulting from off gasing, or other emissions. They conclude that the use of fly ash in cement does not constitute a significantly different radiation risk than the cement it replaces, and neither is it greater than the risk posed by common soil.

3.0 Current Usage

3.1 Agency Requirements

CALTRANS has recently approved a standard special provision, which will become part of their standard specifications when the new edition is released. This special provision requires that mineral admixtures be replaced for cement in all concrete mixes. For fly ash, the minimum required percentage is 15% and the maximum is 25%[8].

ASTM is currently voting on a ballot item that would modify their long-standing masonry grout specification to allow for use of fly ash. Fly ash is already allowed in masonry block production.

Public Works and Government Services Canada (PWGSC) is proposing to adopt the following principal clause for the use of fly ash in concrete for all PWGSC projects:

ΑAll concrete shall contain fly ash or ground blast furnace slag as partial replacement for cement unless it can be shown that the incorporation of these materials is technically and/or economically unfeasible.≅ The ratio of fly ash is to suit the project requirements based on guidelines. These currently allow for up to 60% replacement of cement with fly ash in applications that require both structural strength and consideration of heat of hydration.

Proposed Danish concrete material standards allow for fly ash replacement without a limiting maximum percentage in passive environments.

[8] John Madderom, P.E. SEAOCC perspective newsletter., 1997; Caltrans 1999 Special Provisions

In summary, many agencies allow fly ash and even mandate its use - at up to 35% levels. There are codes currently being developed that would recommend the use of HVFA where heat generation is a concern, such as footings. However, for many of the concrete elements used in station applications, HVFA would be somewhat of a pioneering effort.

3.2 Specific Projects

The following table indicates selected relevant projects that have used fly ash. The table highlights the following:

- Local projects that have used some level of fly ash replacement,
- Precast or post-tensioned projects that used fly ash
- General projects that used HVFA concrete in a structural application.

As the table shows fly ash concrete is not a new product and HVFA is not without precedent.

TABLE 2

#	Project	Element	Fly Ash Replacement Level	Contractor
1	Confederation Bridge (100 year design life)	All members. Substructure and superstructure. Massive elements - girder slabs near piers.	15% 29%	Straight Crossing Inc.
2	Vancouver SkyTrain Extension - RTP2000	Post tensioned segmental guideway beam elements New Westminster Tunnel New Westminster Special Structure - Footing	10% 25% 40%	SAR Transit Walter BFC Peter Kiewit and Sons
3	Liu Center - U.B.C.	Walls, columns, footings	50%	Haebler Construction
4	Madison Development, Burnaby	Parkade slab	33%	
5	Lafarge Dry Kiln Upgrade - Richmond, B.C.	Footings - 6500 w.yds	65%	PCL
6	Vancouver Airport Expansion	Parallel runway	25%	Peter Kiewit and Sons
7	Washington Dept. Of Transportation	Highway 9 Overpass Bridge Overlay	31%	
8	Parlane Development - Halifax, N.S. (1987)	First level cast-in-place columns and beams	55%	
9	Purdy=s Wharf Development, Halifax, N.S.	32-1900 mm drilled caisson footings.	55%	
10	NFESC, Point Mugu, CA Naval Air Station	New runway	30%	

In addition to local projects on this list, Engineers have used up to 40% fly ash replacement locally for mass concrete units, including raft foundations for high-rise buildings and industrial installations. Some examples include the main pile caps of the Alex Fraser Bridge (30%), Pacific Press Kennedy Heights Plant (40%), Lions Gate Bridge South Tower Protection Collar (40%) and the Horizons at Richmond Centre (40%). Also the new B.C. Gas building has been using varying levels of fly ash with cement replacement levels between 0% and 40%.

4.0 Local Industry

4.1 Concrete Batch Plants

Ocean Cement has performed mix design and supplied HVFA concrete for all vertical elements at UBC=s Liu center. They are comfortable with its use and have done recent local floor slabs at roughly 33% fly ash replacement level without noting placing or finishing problems.

Lafarge used HVFA concrete for the footings of their new Richmond dry kiln upgrade.

Almost every ready mix supplier in the Vancouver area has experience with the use of fly ash.

4.2 Precast Plants

We spoke to both major precasters in the Vancouver area, ConForce and APS. We did not speak to out of town suppliers as the weight of the platform pieces will not meet shipping restrictions.

Optimization at precast facilities occurs when elements are repeatable and forms can be stripped quickly. Ideally crews should strip forms within 16 hours of completion of placing. This represents a curing time to achieve a daily cycle. Because fly ash generally increases curing time, neither plant we spoke to has used a significant amount of it in the past. Nevertheless they are not completely unfamiliar with it. Con Force has used fly ash for specific projects in small ratios and APS uses it to achieve color requirements for architectural panels.

ConForce is currently installing a third silo, which they indicated could be used for mineral admixtures. Installation of this silo will be completed prior to the production of station platform beams. APS has no plans for a third silo but would install one if fly ash becomes more common, or is mandated. For the station contract, APS would achieve fly ash contents by the use of bagged product added manually to the mixers.

In summary, precasters are primarily concerned with maintaining production. If required to use a fixed percentage of fly ash, they would increase the overall cementitious content of the mix before leaving the beams in the forms an extra day. Therefore, a mandated percentage of fly ash for precast production must consider cycle times, otherwise it will result in less than optimum material usage and defeat the primary goal of material greenhouse gas reduction.

4.3 Contractors

Contractors have some familiarity with fly ash and will not react strongly to its proposed use. Contractors will react favorably to the workability of the fly ash mixes in general. A workable mix often saves money and time in sacking and finishing.

Their primary concern will be the delays associated with curing. A finishing delay on a long slab pour may raise costs as well as intrude into noise bylaw hour restrictions. Usage of HVFA in columns may require the use of an extra set of forms. Column and wall forms are, like precast elements, typically geared around a 16-hour cure time before stripping. This requirement is governed as much by crew utilization as formwork costs.

5.0 Proposed Usage

5.1 Station Components

The Gilmore and Brentwood stations incorporate the following concrete components:

TABLE 3

Element	Gilmore	Brentwood
Concrete Infill for Steel Pipe Piles	Y	
Pile Supported Slab with Slab Band	Y	
Slab on Grade		Y
Massive Footings		Y
300 - 900 dia. Concrete Columns	Y	Y
Service Area Walls	Y	Y
Service Area/Grouted Block Masonry Walls	Y	
Mezzanine Slab and Beams	Y	
Precast Pedestrian Walkway Beams		Y
Pedestrian Walkway Slab		Y
Trapezoidal Box Girder Platform Beams	Y	Y
100mm Platform Beam Topping	Y	Y
175 Platform Slab Supported by Steel/Concrete Beams		Y
Concrete Infill for Steel Stairs	Y	Y
Concrete Stairs Ground Floor to Mezzanine	Y	

Some of these are immediately recognizable candidates for HVFA. Others have obstacles, which need to be overcome.

5.2 Placing

As mentioned earlier, high volume fly ash mixes will pump and place easier than conventional concrete. Because of the delay in curing and their associated low water contents the steel trowelled finish, where required, will take slightly longer. These finishing differences are minor and are not expected to make HVFA concrete a major concern for Contractors.

The major potential risk involved in placement is the time required for form removal.

5.3 Curing

Curing is critical for all concrete but some research suggests curing is more significant for fly ash concrete than plain cement concrete.

CANMET currently is performing research on local aggregates and with mix designs that are more suited to the precast industry. The research will confirm that the cover concrete features of permeability and porosity are not substantially affected by the accelerated curing performed in the precast plant.

5.4 Costs

HVFA concrete mix will be of equal cost to a conventional cement mix, and possibly cheaper. Suppliers are reluctant to divulge specific mix costs, however the ingredients cost less for the HVFA mix. Extra cost, if any, for superplasticizers and air entraining agents will be more than offset by the fact that fly ash is roughly half the price of cement. The cost of placing HVFA concrete is marginally less and finishing costs marginally more. Some contractors may elect to apply a premium to the product based on its newness but these will likely not be successful.

Extra costs may accrue as a result of using bags to batch concrete if that option is employed. A typical fly ash bag is 30kg. A 60m cu.m. pour requires 7200 kg of fly ash which amounts to 240 bags. The labor involved in that operation should not be ignored. Ready mix suppliers in this position are few.

Increased construction cost likely will not arise as a result of curing requirements - these are part of every specification at present, and, while requiring enforcement are not difficult to implement.

6.0 Recommendations

6.1 General

Based on our review of the literature, the present field experience and discussions with Contractors, researchers and suppliers we recommend that the RTPO adopt the proposed position of CALTRANS and PWGSC and mandate a minimum level of fly ash replacement for all concrete on the Project. We recommend that the minimum level of fly ash be specified as 30% to 35% of the weight of the total cementitious materials. This minimum standard is a significantly greater fly ash volume compared to typical concrete construction.

We also recommend that certain elements, such as footings, walls and columns be specified as HVFA Concrete.

The following table correlates each station element to recommended fly ash replacement level. Note that elements specified as AHigh Volume≅ would use a 50% fly ash mix, a sample of which is shown as Mix 5 of Table 1, and the elements shown as ANormal≅ would use a 30% - 35% fly ash concrete mix, a sample of which is shown as Mix 4 of Table 1. The specifications would not outline mixes themselves but rather give performance criteria such as maximum water, and minimum fly ash ratios. Details are given in the specification section of this report.

TABLE 4

Element	Gilmore	Brentwood	Approximate Concrete Volume (both stations) cu.m.	Approximate Cement Reduction (kg)
Concrete Infill for Steel Pile Pipe Piles	HVFA	N/A	50	7500
Pile Supported Slab with Slab Band	HVFA	N/A	370	55000
At Grade Slab	N/A	HVFA	10	1500
Semi Massive Footings	N/A	HVFA	300	45000
300 - 900 dia. Concrete Columns	HVFA	HVFA	18	2700
Service Area Walls	N/A	HVFA	60	9000
Grout for Masonry Walls	HVFA	N/A	35	5000
200 Mezzanine Slab and Beams	Normal	N/A	190	20000
Precast Pedestrian Walkway Beam	N/A	Normal	220	23000
225 Pedestrian Walkway Slab	N/A	Normal	190	20000
Trapezoidal Box Girder Platform Beams	Normal	Normal	450	47000
100mm Platform Beam Topping	HVFA	HVFA	60	9000
175 Platform Slab Supported by Steel Beams	Normal	Normal	45	4700
Concrete Infill for Steel Stairs	HVFA	HVFA	15	2400
Concrete Stairs Ground Floor to Mezzanine	Normal	N/A	10	1100
Platform spandrel beams	N/A	Normal	180	19000

The primary factors mitigating against the use of HVFA concrete in precast at this time are following:

- The precasters current lack of experience with the material and mixes. There is a real possibility that such a specification would eliminate one of the two suppliers.
- The concern that precasters will load a HVFA flyash mix with excess cement to achieve early strength thus somewhat overshadowing the goal of the project - to reduce material consumption.
- Concerns such as composition of cover concrete under accelerated curing are not seen as significant at this point, but are nevertheless unresolved.

The recommended move to require precasters to incorporate 30% fly ash range at this time will be a significant change from past practice and, we believe, a manageable change that is prudent at this point in time.

The other members not recommended for HVFA concrete are elevated slabs which are thin members and thus not ideally suited to HVFA. They are subject to chilling as they will be exposed top and bottom during curing. The main stairways are high traffic areas subject to frequent applications of de-icing salts and while scaling would not become a 100 year design life issue from a structural standpoint, it may present some maintenance concerns that jeopardize its ability to provide long term service.

6.2 Tendering

We recommend that the base bid and specification require fly ash contents as above. We support the staged approach to the use of fly ash. What we are trying to do is encourage the concept. This would not be accomplished if there are major negative reactions from the contractors or suppliers.

Construction cost increases, if any, will almost entirely be attributable to schedule effects. Some premium for HVFA concrete in wall and column elements may occur. Also, due to the disparity of familiarity among suppliers, some premium may occur as a result of the requirement to use 30% fly ash in precast.

Should the Contractors desire earlier cast-in-place strength for their own construction sequencing, they can accomplish this by adjusting the mixes by increasing cement content (thus with a mandated fly ash percentage increasing overall cementitious content as well.) In this way the specification does not dictate material frugality, but rather leaves some of the economics of schedule costs versus cost of mix in the Contractor=s hand.

In order to obtain some indication of the cost premium involved, if any, we also recommend a line item in the bid that allows for a lump sum credit for the release from any mandated fly ash restrictions. This option should be identified as exercisable by the Owner at his discretion.

We recommend making curing a pay item for all concrete items. A sample measurement and payment line could read as follows:

> *Curing for concrete will be considered as consisting of 10% of the total unit price per cubic metre of concrete bid. Contractor shall provide verification in the Quality Control Plan that concrete has been cured in accordance with Standard Specifications section 03300 to receive this portion of concrete payment. Payment for curing will also include all costs for containment and drainage for curing water and ensuring water does not fall on adjacent roadways or shoulders or impede traffic movement in any way.*

We also recommend that contract language allow for relaxation of the minimum fly ash requirement when concrete is placed in temperatures below 5 degrees Celsius.

6.3 Specifications

The following changes in RTPO=s Standard Station Specifications will accommodate the above proposals:

Section 03110 Structural Cast-in-Place Forms

The section on formwork is generally suitable and requires only minor modifications. We recommend that clauses 3.7.4.1 and 3.7.4.2 be revised to 5 days and that all of the strength references in clauses 3.7.4 be changed to 56 days from the existing 28 days.

Section 03300 Cast-in-Place Concrete

As part of clause 1.1, we would add an additional clause 1.1.2 stating Athe intent of this Specification is to require higher than normal amounts of fly ash as a replacement for Portland Cement≅.

In clause 1.3, add 1.3.5 - CSA A23.5 ASupplementary Cementing Materials≅.

In clause 1.4.1.3 add AΨand mill certificates for supplementary cementing materials≅.

In clause 2.1, add 2.1.3 Afly ash shall comply with CSA A23.5, Class F or Class C1≅.

Delete all of clauses 2.5.4, through 2.5.7 and paste them as clause 2.8 under heading of, ARequirements for Concrete Without Fly Ash Limits≅ with an introductory clause that says the requirements of this section only apply if the Owner elects to exercise the option of relaxing fly ash requirments.

Clauses 2.5.4 through 2.5.7 can then be replaced entirely by the following:

Concrete Requirements

Location (%) Factor (kg/m ^{3})	**Compressive Strength @ 56 days MPa**	**Minimum Replacement: Fly Ash for Cement (1) (%)**	**Maximum Size Aggregate, mm**	**Maximum Water/ Cementing Materials Ratio**	**Minimum Cement kg/m3**	**Air Content + 1-1/2%**	**Slump ± 30 mm**	**Maximum Fine Aggregate (2) (%)**
Block Fill Grout	20	50	10	N/A	N/A	5-1/2	180	60
Precast Concrete	45	30	20	0.38	N/A	5-1/2	80	35
Footings	30	50	40	0.45	175	6	80	40
Infill for Piles	30	50	40	N/A	N/A	4-1/2	180	45
Columns, Walls	35	50	20	0.42	200	5-1/2	80	40
Slabs-on-Grade	30	50	20	0.45	175	6	80	40
Suspended Slabs	30	30	20	N/A	175	5-12	80	40
Topping	30	25	10	0.45	185	4	80	40
Infill for Stairs	30	50	10	0.45	185	5-1/2	80	45

Notes:
(1)Replacement is mass of fly ash as a percentage of total mass of cementing materials.
(2)Fine aggregate as a percentage of total aggregate.

When ambient temperature is less than 5°C, the Contractor may apply to the Owner for approval of concrete mixtures with lower fly ash contents than indicated above.

Section 03350 Concrete Finishing

HVFA does not require any changes in this specification. We note no particular requirements for colour uniformity but such requirements are extremely difficult to enforce.

Section 03450 Precast Architectural Concrete

Add the requirement for supplementary cementing materials to Section 1.3.

Replace clause 2.4.5 with Aconcrete properties shall comply with the requirements for pre-cast concrete in 03300≅.

We note the requirements in clause 2.7.8 which again are more than adequate for our purposes.

Proposed Special Provisions Manufacture and Erection of Precast and Prestressed Concrete Members

Add a paragraph in section 1 as follows:

It is the intent of this specification that concrete used for precast members contain a higher dose of fly ash than normally used for precast concrete. Fabricators are alerted that this may affect setting time, workability, rate of strength gain and timing of stress transfer. Appropriate adjustments to the fabrication process may be required.

Add a new clause in section 2 as follows:
h) Supplementary Cementing Materials

Supplementary cementing materials shall conform to CSA-A23.5, ΑSupplementary Cementing Materials≅. Fly ash shall comply with the CS A23.5 requirements for TYPE F or Class C1 fly ash.

Revise paragraph g) as follows:

Replace CAN3-A266.2 with ASTM C494
Replace CAN3-A266.1 with ASTM C260

Section 13 Admixtures

Add a clause as follows:

Based on the assumption that superplasticizers assist in better dispersing the fly ash concrete mixes, the Owner encourages the prudent use of superplasticizers.

Section 15 Mix Requirements

Add a line as follows:

ΑThe concrete mixture shall contain Class F of Class C1 fly ash at an amount equal to 30% by mass of the total cementing material.≅

Section 19 Test Cylinders

Paragraph b) change age of testing acceptance from 28 days to 56 days.

Section 21 Curing

Replace first sentence with ΑCuring shall comply with the requirements of CS A23.4. During the initial period members may be cured by steam or heat as outlined herein.≅

7.0 Conclusion

In summary, upon review of the available local materials and their effects on concrete, as well as local construction industry practice, we recommend that the RTPO promote increased levels of fly ash in their SkyTrain station tender documents. We recommend that the Brentwood and Gilmore tender, including platform beams, be structured to mandate fly ash at reasonable levels. We believe that this approach will not overly concern Contractors. This report provides modifications to the existing specifications to accomplish the proposed project delivery, varying the required fly ash level for specific elements. For uniformity, adoption of fly ash could be extended to all stations with only slight modifications to the proposed specification.

From our review of literature and our discussions with material engineers we conclude that the adoption of this policy will provide no decrease in material durability in comparison to conventional concrete. The use of fly ash will also be consistent with Canada==s commitment to reduce greenhouse gas emissions.

Appendices

- Busby + Associates Architects Letter
- Centralia and Sundance Fly Ash Sample Properties
- Sustainability in Construction - Use of Fly Ash As a Cement Replacement - P.T. Seabrook, P.Eng.