ADDRESSING REGIONAL SUSTAINABILITY : A CASE STUDY OF LITTLE MOUNTAIN RESERVOIR RECONSTRUCTION USING CONCRETE CONTAINING LARGE VOLUMES OF FLY ASH

By

A.P. Sukumar
Phil Seabrook
John Sherstobitoff
Frank Huber

Synopsis: The Little Mountain Reservoir located in Queen Elizabeth Park, Vancouver, British Columbia, Canada was originally constructed as an open basin in 1910 and a roof structure was added in the mid 1960s. Because of seismic and structural deficiencies of the structure, it was decided to demolish the reservoir and construct a new one on the same site with increased capacity and enhanced operational flexibility. Demolition of the existing reservoir began in September 2002 and construction of the new facility was substantially complete by December 2003. Regional sustainability principles have been incorporated into the design and maximum feasible amounts of fly ash were utilized for all concrete components in this project. The concrete specification recognized the difference between winter and summer replacement levels of fly ash, addressing schedule and constructability constraints. The resulting concrete met or exceeded the specified requirements, provided excellent surface finish, and the project was completed within the tight schedule. This paper presents the approach used to achieve sustainable concrete generally, and specifically the properties of the concrete with large volumes of fly ash used in achieving high quality concrete with an anticipated 100 year service life.

Keywords: concrete, greenhouse gas, fly ash, EcoSmart, infrastructure renewal, mixture proportions, supplementary cementing materials, sustainability, water reservoir.

ACI member Dr. A.P. Sukumar, MBA, P.Eng., S.E is the Project Manager of the Little Mountain Reservoir Project and the Senior Engineer, managing the structural engineering group at the Greater Vancouver Regional District Vancouver, B.C, Canada. He is an engineer registered in Canada & United States and is a recipient of the first annual APEGBC Sustainability award.

ACI Fellow, Phil Seabrook P.Eng, PE, is Executive Vice President of Levelton Engineering, a consulting Materials Engineering firm. He has been deeply involved in the development and implementation of sustainable concrete in Western Canada. Phil serves on the Steering Committee of EcoSmart and on the Canadian Standards Sub-committee on HVSCM.

John Sherstobitoff, M.ASc., P.Eng., is the Design Manager for the Little Mountain reservoir Project, and the Manager of Buildings and Infrastructure at Sandwell Engineering Inc., the prime consultant on the project. John is a Seismic Specialist with expertise in structural and seismic rehabilitation. He has incorporated concrete with large volumes of fly ash in numerous projects

Frank Huber, M.Eng., MBA, P.Eng., is the Division Manager for Engineering Support and Technical Services at the Greater Vancouver Regional District, the division responsible for the Little Mountain Reservoir Project. He sits on the EcoSmart Concrete Steering Committee and is a recipient of the first annual APEGBC Sustainability award.

INTRODUCTION

The Greater Vancouver Water District (GVWD) operates under the umbrella of the Greater Vancouver Regional District (GVRD), in the province of British Columbia, Canada. The GVWD owns and operates the water transmission system that brings potable water from the source to most residential, commercial and industrial taps in the region. It provides a safe and reliable supply of drinking water to 18 municipalities, meeting the multiple needs of approximately 2 million residents in the area.

The water from mountain creeks and streams is collected in three protected watershed areas – Capilano, Seymour, and Coquitlam, located in the Coast Mountains immediately north of Greater Vancouver. Water is collected and distributed to the municipalities via an immense network comprised of six dams, 22 distribution system reservoirs, 15 pumping stations and over 500 kilometers of supply mains. The average water consumption in 2003 was approximately 1,185,000 cu.m per day, making the system one of the largest in Canada.

Little Mountain Reservoir located in Queen Elizabeth Park, the highest geographic point in the City of Vancouver, is the largest and most important distribution reservoir in the GVWD system. It was originally constructed as an open basin in 1910 and a pre-cast concrete roof structure, subsequently used for parking and recreational purposes, was added in the mid 1960s. In the 1990s, investigations determined that the concrete roof structure and the surrounding earthen containment berm did not meet modern seismic criteria. Even a moderate earthquake would likely have caused collapse of the roof and breaching of the embankment resulting in a sudden release of up to 138,000 cu.m of stored water. It was decided to reconstruct the reservoir on the same site as a concrete structure independent of the containment berm, with increased capacity and enhanced operational flexibility. The new structure is anticipated to have a 100 year service life.

REGIONAL SUSTAINABILITY INITIATIVE

The Greater Vancouver Regional District (GVRD) has considered economic, social and environmental perspectives in project design for many years. This has often included substantial public consultation programs to ensure that a broad range of opinions/ideas could be considered as part of project design. However, at times, all 3 components were not necessarily considered from a balanced, systems perspective, or addressed consistently from project to project. Advancing sustainability is clearly about recognizing and considering the links between economics, social impacts and the environment. Over the past few years, the GVRD has taken on a leadership role on sustainability and sustainable design, through the Sustainable Region Initiative.

A number of task groups have been established with other public and private sector organizations to promote regional sustainability and to provide guidance that will result in common practices throughout the region. Internal to the organization, similar task groups have been established to formalize sustainability considerations into corporate policy and into routine day to day work practices by staff. This has resulted in many projects now considering such approaches as LEED’s (Leadership in Energy and Environmental Design) Building design classification, multiple uses of a single property (i.e. utility and recreation), using concrete with large volumes of fly ash, and so on.

At the conceptual stage of the Little Mountain Reservoir Reconstruction (LMRR) project, the corporate direction to the design team was to seek and utilize technologies that would address environmental, social and economical issues in a balanced manner.

PROJECT CHALLENGES

Located in the environmentally sensitive and scenic Queen Elizabeth Park, the LMRR posed many challenges to the team (Figs.1, 2). The construction window allotted for the project was limited to the low water demand months of the year, September 2002 to May 2003, during which alternate infrastructure kept up the necessary water supply. The new reservoir has been designed as a twin-celled facility of which each cell can operate independently. Cell 1 of the reservoir, and a state of the art valve chamber that serves both cells had to be ready for service by May 2003 making the construction schedule extremely tight. The new reservoir with a capacity of 175 million litres (39 million Imp. gallons) is an increase of 25% from the original capacity, and is built on the same footprint as the old one which is approximately equivalent in area to two and a half football fields.

The site is in the middle of the City of Vancouver surrounded by one of the most beautiful parks in the region and the construction work naturally created extensive public interest. The reservoir roof top was being used by approximately 500 people practicing Tai Chi exercise every morning; they were relocated to a suitable venue offsite for the duration of construction. Access to the construction site required sharing and maintaining the same road that tourists use to access an adjacent conservatory and a prominent restaurant in the Park. The old reservoir had to be completely demolished and the material disposed of before new construction commenced. All the demolished concrete was required by specifications to be disposed of to recycling plants and in order to ensure proper recycling, the concrete and reinforcing bars were separated on site. Excavation and vertical shoring through 9 m of embankment for the reservoir perimeter walls was also a challenging and time consuming portion of the work.

The key principles and design criteria that had to be addressed by the designers were:

- The 100 year service life without major maintenance;
- Security of water supply;
- "Crack-free" construction and a minimum number of construction joints;
- Low concrete permeability and suitability for potable water storage;
- Constructability, particularly as it relates to concrete placing, curing and finishing;
- Production of a smooth surface (free of bug holes) to avoid breeding areas for bacteria;
- Ability to survive the maximum credible earthquake (MCE -1/10,000 year return period) for the site, and remain functional, and
- Ability to sustain bus loading of the roof, and simultaneously meet the water quality goal of zero permeability through the roof slab.

RESERVOIR STRUCTURE - DESIGN

The following principles and criteria were incorporated in the structural design of the reservoir:

- The structural concept is a monolithic roof/wall/slab construction with no expansion joints, that is very efficient to resist earthquake loads from external soil pressures, internal sloshing effects, and inertial loading of the structure itself, in combination with the normal hydrostatic loading.
- Widely spaced construction joints were achieved using full height (9m high) wall placements some 14.6m in length, base slab placements of 14.6m by 14.6m in plan area, and roof slab placements of some 850 sq m or 260 cu. m. each. The limited amount of joints, all water-stopped and sealed, is intended to reduce leakage potential and long-term maintenance.
- “Crack free” meant limiting cracks to less than 0.2mm (BS 8007, CSA 23.3 and ACI 350) in width for the base slab and walls, to enable ‘self-healing’ and thus essentially eliminate long-term leakage through the concrete. Closely spaced reinforcing steel was required to achieve this criterion.
- The use of a roofing system with very stiff insulation and a double membrane ensured heavy wheel loads could be supported, thermal strains on the monolithic expansion joint -free structure were minimized, and the roof permeability was zero.
- The use of the highest feasible volume of fly ash in the concrete within the project constraints. The amount of fly ash replacement was specifically designed for each component of the reservoir to enable placement compatible with the rebar detailing and placement size. Curing and finishing requirements were clearly specified. Achieving the features of strength, permeability, durability, and finish that were critical to the success of the project. With regard to the permeability and durability, much reliance was placed on the work by Malhotra and Mehta, (5) and previous related publications by those authors, which shows superior long-term values for HVFA concrete. While the referred system uses 50% of fly ash replacement as a base, for constructability and schedule considerations, lower replacements were specified for this project.

CONCRETE WITH LARGE VOLUMES OF FLY ASH (LVFA)

Production of portland cement is known to be high on energy consumption and to contribute to significant amounts of carbon dioxide (CO2) emissions to the atmosphere. According to greenhouse gas emission (GHG) statistics related to concrete production, every tonne of cement production contributes nearly one tonne of CO_2 emission into the atmosphere (1). Research and case studies have addressed the issues related to usage of cement in concrete production by appropriately replacing it with suitable supplementary cementing materials (SCM). Malhotra (1) addressed the role of fly ash and other supplementary cementing materials in the sustainable development of cement and concrete industry. Mehta (2) cites examples of concrete mixtures containing more than 50% fly ash that have produced high strength and durability at relatively early ages. Recently, Obla, et. al., (3) provided an industry perspective of fly ash content related to specific use of concrete based on practical applications, including the concrete finishing requirements. In Canada, there have been successful construction projects that incorporated large volumes of fly ash in the concrete mixtures (4). In line with the GVRD's Sustainable Region Initiative policy, the corporate management gave support for the usage of maximum feasible amount of fly ash in the reservoir concrete mixture if it complied with all the project requirements and schedule milestones to meet regional demand for potable water.

Concrete with Large Volumes of Fly Ash (LVFA) has become known in Western Canada as EcoSmart concrete. EcoSmart is a joint venture of GVRD, Environment Canada, and Industry Canada, which has the objective of developing partnerships with industry to minimize the GHG signature of concrete by replacing a portion of the portland cement with SCMs. It is EcoSmart's approach that such concrete should have:

- the same or better durability;
- the same or lower cost; and
- similar ease of construction as concrete with straight cement.

It is normal to use as much as 20 to 25% fly ash replacement for cement in concrete in British Columbia. However, use of higher volumes of fly ash has typically, and predictably, created mixed reactions from the contracting community. Lack of experience with the product as well as the perceived difficulties and costs in handling and/or dealing with formwork loadings for the LVFA concrete mixture have been discussed in many contractor forums. The impact on construction schedule is always an issue which the contractors must critically evaluate when working with LVFA concrete. In the LMRR project contract, there was a liquidated damage clause which stipulated that the contractor will be responsible for all costs associated with disrupted water supply, should there be a delay in completing the project on time. The formwork stripping time for certain concrete elements may end up being longer for concrete with LVFA because of the slow gain in strength, and there may be finishing issues with the extended setting time. Without prior experience and continued support from the consultants, owners and the concrete suppliers, contractors typically tend to stay with conventional construction unless new materials and methods are stipulated in the contract.

In the LMRR project, the right elements were combined to produce a sustainable concrete that met or exceeded the project specifications (Table 1). The concrete specification was performance based. Enough flexibility was allowed so that the concrete mixtures could be altered appropriately as long as the overall fly ash utilization target for the project was achieved. Extensive studies were done by the concrete supplier prior to finalizing a series of concrete mixture proportions suitable for the project. The contractor and the concrete supplier were interested in finding an optimal set of concrete mixture proportions that met the performance specification, could work within the tight schedule, and be readily constructible.

Table 1 illustrates the approach to specifying EcoSmart concrete on a performance basis, along with selected Mixture proportions. Note that:

- There are different minimum fly ash replacements for Cell 1 which was to be largely constructed in the winter and Cell 2 which was to be largely constructed in the summer;
- There are also different replacements for different structural elements, recognizing the relative impact on constructability.
- A shrinkage-reducing admixture was included in the critical base slab concrete in order to minimize the risk of cracking.
- A minimum coarse aggregate content was specified to achieve reasonable volume stability.
- The W/C requirements were designed to achieve both low permeability and long-service life.
- A 56-day strength acceptance age was specified to take advantage of the slower strength gain of this EcoSmart concrete.
- Superplasticizers were mandated for the wall concrete because the walls are about 9m high and difficulties in segregation and consolidation were anticipated for the full height placements. However, due to the contractor's excellent concrete placing procedures, he was granted permission to reduce the superplasticizer, and therefore the slump, in the interests of avoiding further setting time delays.

There were also significant volumes of structural shotcrete (Fig. 3) and lean-mix concrete that utilized larger volumes of fly ash in the mixture.

CONCRETE PROPERTIES

Mixture Proportioning

The supplier's mixture proportions readily met or exceeded the specified requirements (Table 1). In most cases, the supplier chose higher fly ash replacements than the minimums specified. The fly ash used was a Type C1 as defined in CSA A3000 (Table 2) and cement was Type 10 (Table 3). This ash has a long history of excellent performance in local concrete; it can generally be substituted for cement on a mass for mass basis.

Fresh Concrete Properties

Concrete with the levels of fly ash specified (Table 1) has a tendency to be sticky. Figure 4 shows that it hangs on rebar but readily responds to vibration and it is readily pumpable.

As indicated above, delayed setting time can be expected with LVFA concrete. Figure 5 shows the results of tests during winter and spring conditions. The two curves are similar. Given the differences in temperature, corresponding differences in setting time would have been expected. For comparison, a typical summer setting time curve for a straight portland cement mixture is also shown in Fig. 5.

Concrete containing fly ash normally does not bleed. However, some of the initial slab concrete placed had a high level of bleeding; later concrete did not have this characteristics and the reason for the difference was not determined. A test for bleeding on the wall concrete showed only a trace, not measurable by the ASTM C232 procedures.

Hardened Concrete Properties

Table 4 presents a statistical analysis of the 56 day compressive strengths. Analysis was conducted in accordance with ACI 214 procedures. Figure 6 shows typical age vs. compressive strength results. The concrete is readily exceeding the required 35 MPa in 56 days. This represents the conservative approach taken by the supplier in developing mixture proportions.

Shrinkage tests were conducted in accordance with ASTM C157 procedures using the 28 day initial moist curing regime. Results are presented in Fig.7. It is noted that the shrinkage reducing admixture significantly reduced the shrinkage for the slab mixture to roughly two-thirds those of the wall mixture. Results of this slab test showed 28 day shrinkage values slightly exceeding the maximum 0.03% specified. Figure 7 also shows the shrinkage of companion wall mixture prisms that were field cured at the same temperature as the constructed wall. These values are significantly lower than those tested to ASTM C157 procedures. Although field cured slab prisms were not tested, reduction in shrinkage of slab prisms similar to that of wall samples can be expected and the actual field shrinkage value would be less than the 0.03% criteria.

Table 5 presents data regarding the durability and permeability of the concrete. These properties met the project goals of very low permeability for the slab and low permeability for the wall. Note the high resistivities which assure protection of the reinforcement from corrosion.

There were only a few cracks exceeding the specified 0.2mm criteria in any LMRR concrete. Excellent wall formed surfaces were achieved and Figure 8 shows a typical view of the finished concrete roof of the reservoir.

IMPACT OF THE PROJECT - GREEN HOUSE GAS EMISSIONS

Approximately 27,000 cubic metres of concrete was used in the project and half of it contained about 50% or more fly ash. In order to produce 27000 cu. m of conventional concrete, about 9000 tons of portland cement would have been required and correspondingly, the project would have been responsible for approximately 9000 tons of CO_2 emissions. By replacing an average of 41.5 % of the portland cement with fly ash, the project contributed to a reduction of about 3700 tons of CO_2 emissions. There is also considerable energy saving achieved by displacing the production of 3700 tons of cement. The fly ash is a by-product from thermal plants and recycling of this material also represents an environmentally sustainable initiative.

CONCLUDING REMARKS

The LMRR project concrete proved to be excellent in terms of workability, durability properties, strength and finish. When using LVFA concrete, mixtures should be proportioned to suit the requirements of the project, addressing the schedule, weather and constructability constraints

Malhotra and Mehta (5), point out that large scale cement replacement in concrete will result in economy, energy efficiency, durability and it will result in a better overall ecological profile of concrete. The experience of using EcoSmart concrete in the LMRR project supports their conclusions except in the case of ‘economy’ for the owner. The direct cost of concrete for the project, as reported by the contractor, is essentially the same as that of conventional concrete. Although fly ash is an industrial by-product, and roughly one-half the cost of cement in British Columbia, concrete suppliers are yet to transfer any savings to the owners. The concrete supplier indicated that LVFA concrete required more effort in mixture proportioning, quality control testing and in the manufacturing process compared to normal concrete. As the local industry matures to reach a critical mass of concrete production with supplementary cementing materials such as fly ash, it is hoped that the economic advantages can also be realized.

In the global sense, the overall impact of LMRR project may be small, but considering the usage of cement and concrete in Canada for infrastructure renewal projects in general, there is a huge potential to reap from the experience gained. Major infrastructure replacement projects currently being planned in the country will form the basis of construction in the next 50 years and the public sector has a responsibility to help evolve the industry to utilize sustainable materials and methods. It is in this context, the Little Mountain Reservoir Reconstruction Project is making a significant contribution to the construction industry by demonstrating the successful use of concrete with large volumes of fly ash.

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Table 1 - Mixture Proportions

Mixture Specification

Location	Walls & Columns		Roof Slab		Lean Concrete	
Weather	**Winter**	**Summer**	**Winter**	**Summer**	**General**	**Under Fdn.**
Specified Strength @ 56 days	35 MPa	35 MPa	35 MPa	35 MPa	10 MPa	20 MPa
Exposure Class	C2	C2	C2	C2	N	N
Specified Air (+/-1)	5%	5%	5%	5%	6%	6%
Maximum Aggregates (mm)	20	20	20	20	28	28
Fly ash (Minimum %)	35	35	30	30	50	50
Slump (mm) before and after Superplasicizer	60/180	60/180	70	70	150	150

Sample Mixture Proportions* per cubic metre of concrete.

Mixture ID	GVRD 3	GVRD 4	GVRD 5	GVRD 6	GVRD 9	GVRD 10
Portland Cement (kg)	228	200	195	200	100	110
Fly ash (kg)	152	180	195	180	100	150
Fly ash %	**40.0%**	**47.4%**	**50.0%**	**47.4%**	**50.0%**	**57.7%**
Total Aggregates (Coarse & Fine) (kg)	1850	1830	1805	1830	2048	1950
Water (kg)	130	130	130	130	145	150
Air content (%)	5-8%	5-8%	5-8%	5-8%	1-4%	1-4%
Superplasticizer (L)	As required	As required	As required	As required	N/A	N/A
Concrete Volumes (m^3) Total for GVRD 1 to 15: 27000 m^3	2500	2700	3400	3700	4500	200

** Mixture proportions were developed by Lafarge Canada, Inc. (Concrete supplier for the project).*

1- Daniel St-Pierre, M.Sc., P.Eng.: Quality Assurance Manager, Lafarge R &D Lab, Greater Vancouver Area

2- John Anthoine, P.Eng.: Business Performance Manager, Greater Vancouver Area

3- Norm Wood, P.Eng.: VP Quality Assurance and New Products Development, Western Canada

Table 2 - Properties of Fly Ash (Type Cl)

Chemical		**Physical**
SiO_2	56.10%	Fineness, retained 45µm: 13.3%
Al_2O_3	22.60	Strength Activity with cement:
Fe_2O_3	4.60	7day : 87.6% control
SO_3	0.20	28 day : 98.3 % control
CaO	10.60	Water requirement : 94.0%
LOI	0.30	Autoclave Expansion; +0.10%
		Relative Density: 2.06

Tests to CSA A23.5

Table 3 - Properties of Cement (Type 10)

Chemical		**Physical**
SiO_2	20.00%	Fineness, passing 45µm; 98.6%
Al_2O_3	4.80	Compressive Strength
Fe_2O_3	3.60	3 day : 41.3 Mpa.
CaO	65.10	7 day : 42.5 Mpa.
MgO	0.90	28 day : 47.1 Mpa.
SO_3	2.60	Time of Set, Initial: 84 min.
LOI	2.60	Air Content: 5.8%
Na Eq.	0.48	Autoclave Expansion: -0.03%
C_3S	68.00	
C_3A	6.50	

Tests to CSA A3000

Table 4 - Strength Summary @ 56 days

	Slab Concrete	**Wall Concrete**
No. of Test Sets	65	46
Max, (56 days) MPa	60.7	56.2
Min, (56 days) MPa	40.2	35.2
Standard Deviation, MPa	4.1	4.8
Coefficient of Variation, %	8.0	10.1
ACI 214 Uniformity Rating, based on Coefficient of Variation	Very good	Good

Table 5 - Durability Properties

Properties	Slab Concrete	Wall Concrete	Test Procedure
Resistivity ohm-cm	26 600	18 600	ASTM C1202 @ 90 days
RCP, coulombs	789	1 150	
Permeability Rating	very low	low	
Boiled adsorption, %	3.7	5.8	ASTM C642 @ 90 days
Volume permeable voids, %	8.7	12.8	
Unit mass, wet, kg/m3	2459	2335	

Fig.1. Little Mountain Reservoir, Q.E. Park, Vancouver

Before Demolition -August 2002

Fig.2. Little Mountain Reservoir Reconstruction

Work in Progress -June 2003

Fig.3. Applying Structural Shotcrete on Sloping Rock Face

Fig.4. EcoSmart Concrete- Placing & Vibration (Floor)

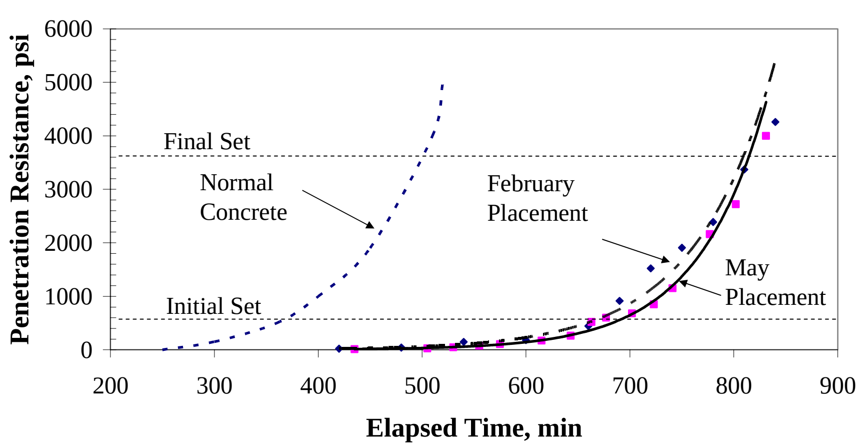

Fig.5. Setting Time for Wall Concrete – Winter vs. Spring

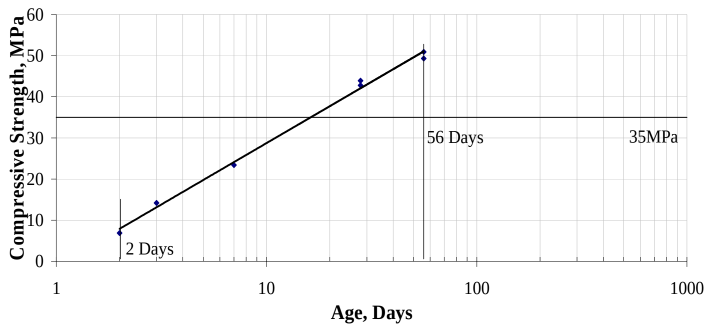

Fig.6. Wall Concrete – Age: Strength Relationship

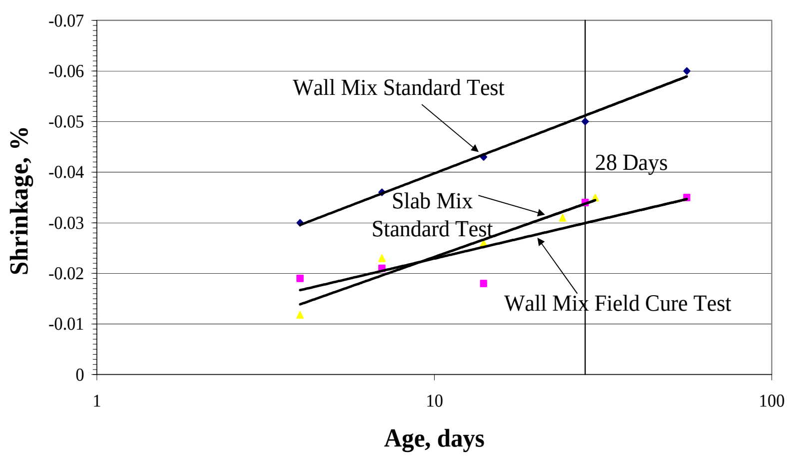

Fig.7. Shrinkage Vs Time (Test Batch)

Fig.8. Concrete Roof and Column Finish