PROPERTIES OF HIGH VOLUME FLY ASH WALL CONCRETE

Little Mountain Reservoir
Vancouver, BC

Combined Phase I and Phase II Report

Prepared for:

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EXECUTIVE SUMMARY

The use of EcoSmart concrete at the Little Mountain Reservoir Replacement Project demonstrates that this type of concrete is ideal for large infrastructure projects. The resulting Wall concrete evaluated here had in excess of 35% fly ash replacement for portland cement.

Design Consultants Sandwell / Associated intended that the use of the EcoSmart concrete here would result in significant GHG reductions at no premium cost. This was achieved. Also achieved was relatively low shrinkage which resulted in crack-free walls and supported control joints at larger than normal spacings.

The concrete had excellent workability resulting in corresponding excellent surface finishes. It was readily pumped and consolidated, even at slumps that would be considered low for the Wall configuration.

High durability, necessary for the 100 year design service life, was demonstrated by low porosity and permeability in concrete tests. In addition, the concrete's high resistivity will assist in long term passivation of the reinforcing steel from corrosion.

As is typical of concretes containing higher fly ash replacements, slower setting times and lower early age strength resulted. However, the in situ strength of the semi-massive Walls concrete was adequate to achieve conventional formwork stripping schedules.

Data obtained here will be of value in future in future GVRD water-containing structure designs.

1.0 INTRODUCTION

The Greater Vancouver Regional District (GVRD) is constructing a new 38.5 million gallon reservoir at Little Mountain, Vancouver. The Project is known as the Little Mountain Reservoir Reconstruction (LMRR).

Appendix A contains a further description of the Project features and some related photographs, and identifies the firms involved.

Concrete for the Reservoir has some unique features dictated by GVRD and implemented by the Design Consultants, Sandwell/Associated Engineering. Included in those features are:

- a 100 year service life;
- an intent to achieve “green” construction within the limits of budget and schedule;
- the use of concrete containing high replacements of portland cement with fly ash in order to achieve durability and workability as well as the GHG reduction benefits. This is what has become known as EcoSmart concrete.

These translated into the following design parameters:

- concrete with low permeability;
- concrete capable of a dense formed surface (free of bug holes) to prevent bacterial growth reservoirs;
- a minimum number of control joints and form ties;
- a target of crack-free concrete.

EcoSmart is a partnership of GVRD, Industry Canada, Environment Canada, NRCan, and the construction industry. It has as its objective to develop partnerships with industry and professionals to minimize the GHG “signature” of concrete by replacing portland cement with SCM or reduce the amount of concrete per use.

EcoSmart’s interest in the LMRR Project relates to its potential to demonstrate effective use of sustainable concrete, consisting of high volumes of SCM replacement, within their policy:

> “To minimize the GHG signature of concrete by maximizing the replacement of Portland cement in the concrete mix with SCM within the parameters of cost, performance, and constructibility”.

This report presents Levelton’s documentation of the properties of the wall concrete. Walls were designed to have the features outlined above which translated into:

- low shrinkage;
- low heat of hydration;
- low permeability;
- high resistivity to produce protection of rebar from corrosion by passivation of the steel;
- ease of placing and consolidation.

Phase I of this program was conducted in accordance with Levelton's proposal of November 28, 2002. Upon completion of Phase I, it was apparent that additional data of interest to LMRR could be obtained from this large infrastructure Project so a Phase II was undertaken. This report combines the work of the two Phases and supercedes the Preliminary Report of April 4, 2003.

Levelton also issued a separate Report on Maturity and early age wall concrete strength gain on April 28, 2003. It is included as Appendix C here.

2.0 OBJECTIVES OF THE PROGRAM

Following are the Phase I program's objectives:

1. To address some of the Technical Issues identified by industry that retard the development of EcoSmart concrete. Specifically it was hoped that information would be provided on these issues:
    - typical shrinkage values for high quality EcoSmart concrete;
    - confirmation of the anticipated EcoSmart concrete properties for:
        - bleeding;
        - workability and surface finish;
        - freedom from cracking;
        - setting time.
2. To define the LMRR concrete properties in such a form that they can be related to:
    - published data;
    - needs for other projects, including those contemplated by GVRD.
3. To present information as a part of the eventual EcoSmart's LMRR Case Study Report.
4. To expand the data base on the performance of local concrete containing higher than normal replacements of cement with fly ash.

Phase II had objectives focussed on specific aspects of Phase I:

- explaining/confirming shrinkage results;
- confirming that the Test Mix sampled for Phase I was not representative of the normal wall concrete;
- obtaining a temperature profile of early age concrete to confirm the expected reduction in heat of hydration.

3.0 PROGRAM METHODOLOGY AND BACKGROUND INFORMATION

3.1 Nature of the Test Walls

3.1.1 Phase I

Reservoir walls are 600 mm thick and about 9 m in height. As such, they are relatively massive sections with concrete placing challenges due to the drop-height of the concrete. There are interior and exterior curtains of reinforcement.

Photographs in Appendix A show features.

The wall selected for test here is in the south side of Cell 1. It was cast on December 12, 2002 when the average daytime temperature was 11°C, and temperature at sampling was 10°C.

3.1.2 Phase II

The Phase II wall panel was placed May 2, 2003, when the average daytime temperature was 13°C, and temperature at sampling was 9°C. It is Panel #32 on the North wall of Cell 2. Dimensions are the same as above.

Photographs in Appendix A show features.

3.2 Specified Concrete Properties

Project Specifications require the wall concrete to have:

- Class of exposure – C2.
- Maximum size aggregate – 20 mm.
- Minimum ratio of coarse:fine aggregate – 62%.
- Minimum fly ash content as a percentage of total cementing materials – 35% for Cell 1 and 45% for Cell 2.
- Plastic properties:
  - Slump - 60 mm before superplasticizer;
    - 180 mm after superplasticizer.
  - Air content – 4 to 6%.
- Compressive strength @ 56 days – 35 MPa.

On the basis of a mix design confidentiality agreement with the concrete supplier, actual mixture proportions cannot be provided. However, Levelton has been able to document that the proportions readily exceed the relevant requirements above. Therefore, it is highly probably that the fly ash content was higher than 35% for Cell 1.

The mix design is identified in the LMRR records as "GVRD 3" for Phase I and "GVRD 4" for Phase II. The difference between the designs is primarily in the removal of the superplasticizer for GVRD 4.

3.3 Concreting

Graham Construction, the Contractor, placed Phase I concrete with a crane and bucket into drop chutes – see Photograph 5. The Phase I test wall was the third that had been placed by Graham. Because of the Contractor's success in placing and consolidating concrete in early stages, changes were made in later concreting. These consisted of:

1. direct placement from a bucket – see Photograph 13 for Phase II;

2. because of the desire to maximize early strength gain, Graham requested, and received permission to reduce the superplasticizer dosage such that the slump was in the 120 mm range.[Note 1:] The 180 mm had been specified to both minimize the need for consolidation, given the wall height, and to ensure encapsulation around the waterstop connecting to the foundation. The 120 mm slump in the high volume fly ash concrete here achieved these objectives equally well.

In order to ensure consolidation of the waterstop, Graham had a workman inside the forms to consolidate the initial lifts of concrete.

Graham wished to further accelerate concrete setting to avoid excess formwork pressures and accelerate the rate of pour. To achieve this, they applied heat to the space between the excavation wall and the backside of the forms for the Phase I pour (heating subsequently discontinued because the ambient temperatures rose and the need for strength acceleration reduced.

Reinforcement congestion is shown in Photographs 4 and 14.

Levelton's Technician made a number of observations relevant to the Objectives in 2.0 during the Phase I pour. These are presented in Appendix B.

3.4 Test Program and Procedures

For Phase I, the Levelton Technician attended the pour and sampled and tested:

- An initial load at 14:00.
- A supplementary load at 16:00.[Note 2:]

The majority of tests were conducted on site except where indicated otherwise below. The Technician's field notes are reproduced in Appendix B.

Phase II tests followed a similar pattern except that only one load was sampled.

[Note 1:] Superplasticizers are set retarders.

[Note 2:] The supplementary load is an addition to the original program. It was taken to provide additional information.

Test procedures were:

- Plastic concrete properties – CSA A23.2.
- Bleeding – ASTM C232.
- Setting time – ASTM C403. Samples were transported from the site to the Levelton laboratory to complete this test.
  - Shrinkage – ASTM C157. All test prisms were cast on site and cured there under cover for the initial 24 hours. For Phase I, the shrinkage test was conducted in 2 modes:
    - **Mode 1:** The Standard procedure which involves 28 day moisture curing followed by drying at 50% RH and 23°C. The Standard tests is normally run to 28 days at the 50% RH curing and results quoted in the literature are typically based on this value. For purposes here, the test was continued to later ages and remains in progress at this writing.
    - **Mode 2:** A field procedure in which samples are stored in ambient conditions, initially on site, then outside at the Levelton laboratory which would have ambient temperatures similar to the site. This is not a Standard test, but was inserted for interest.

For Phase II, tests were conducted in accordance with the Standard (Model) only.

- Permeability – Rapid Chloride Ion penetration procedure on portions of cylinder samples – ASTM C1202 – see Photograph 7. This test also produces resistivity values.
- Porosity – ASTM C642 on portions of cylinder samples.
- Strength properties:
  - compressive – CSA A23.2.9C – on 100 diameter x 200 mm cylinders;
  - maturity – based on 150 diameter x 300 mm cylinders, ASTM C1074;[Note 3:]
  - split tensile – ASTM C496 on 150 diameter x 300 mm cylinders.

[Note 3:] It was intended to use the Maturity curve to determine in situ wall concrete strength for form release purposes. These were not actually used for this purpose, as explained in 5.3.

4.0 RESULTS

4.1 Plastic Concrete Properties

Property	MIX		
	Phase I Test	Phase I Supplementary	Phase II Test
Temperature, °C			
Concrete as sampled	16	17	17
Ambient at sampling	10	10	9
Slump, mm (120 mm intended)	110	100	70
Air, % (4 to 6% required)	4.4	4.2	6.2
Bleeding, %	Nil	N/A	Negligible

The setting times are shown in Fig. 1. An Initial Set of about 11 hours and a Final Set of about 14 hours is recorded.

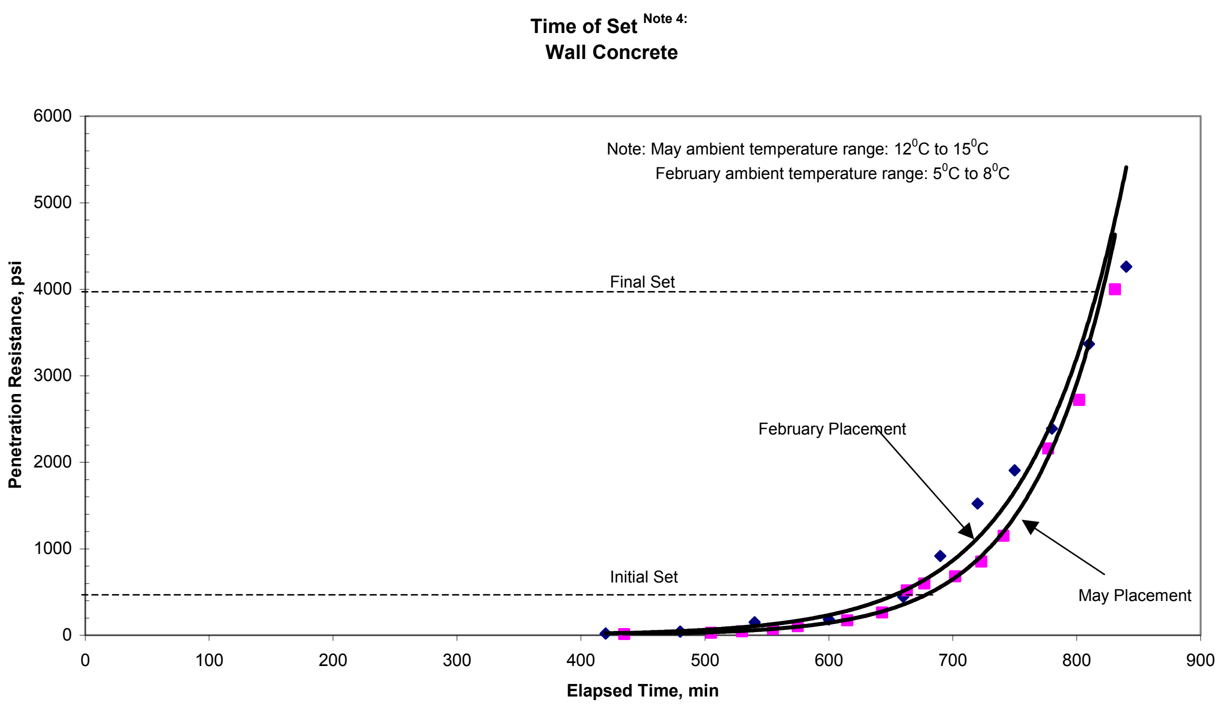


Fig. 1 Setting Time

Note 4: The ambient temperature in Fig. 1 differs from those in 4.1 because in February the sampling was late afternoon and the temperature then dropped. In May sampling was in early morning and the reverse situation occurred.

With regard to the bleeding testing, the technician reported:

- Sample covered with poly and burlap to prevent evaporation.
- No bleeding of note took place on surface of test sample.

4.2 Strength Properties

Fig. 2 presents age:strength results for the three samplings. Results are presented in a semi-log plot because previous experience with similar EcoSmart concrete had shown the classical linearity in this form.

The large discrepancy between the results of the Phase I Test and Supplementary mixes is explained in 5.3.

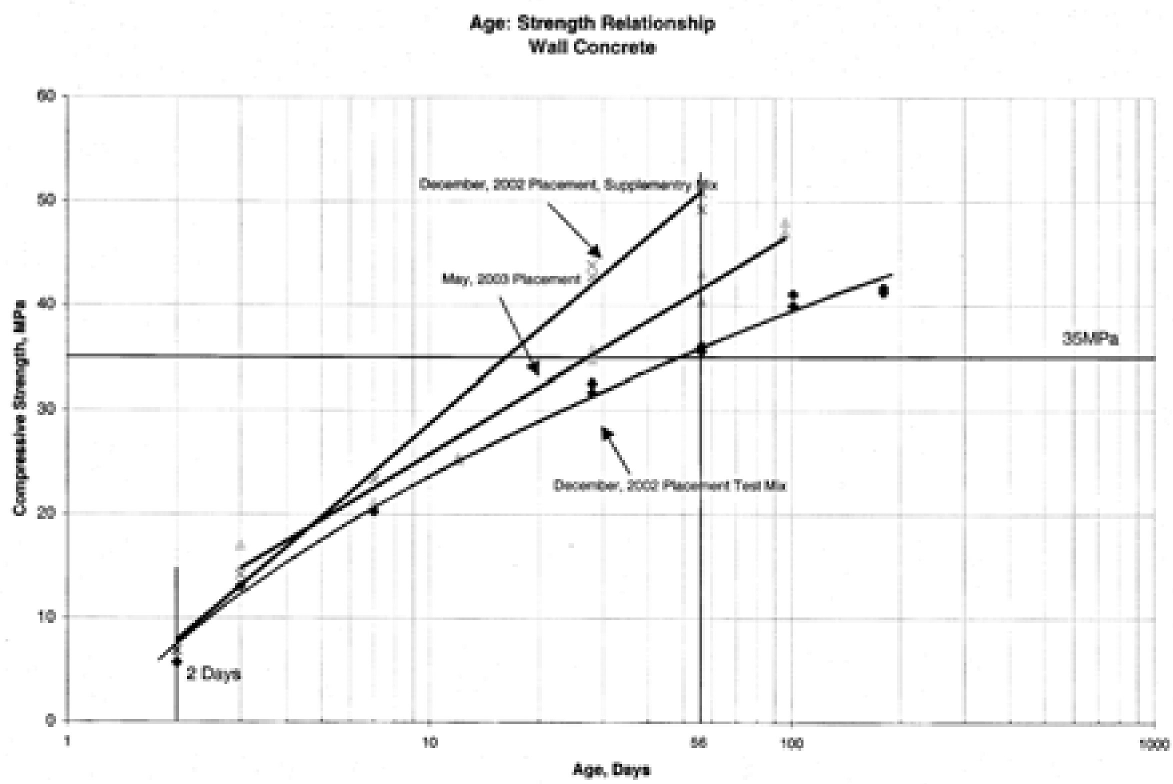


Fig. 2 Age:Strength Results for the Two Samples

Fig. 3 shows the Maturity Curve for the Phase I tests. Further Maturity data is presented in Appendix C.[Note 5:]

Fig. 3 data shows one day in situ strengths of about 10 MPa. Note that:

- These are higher than the strengths of standard cured cylinders;
- 10 MPa is often designated as the minimum strength for form stripping by designers so that could be achieved in one day here.

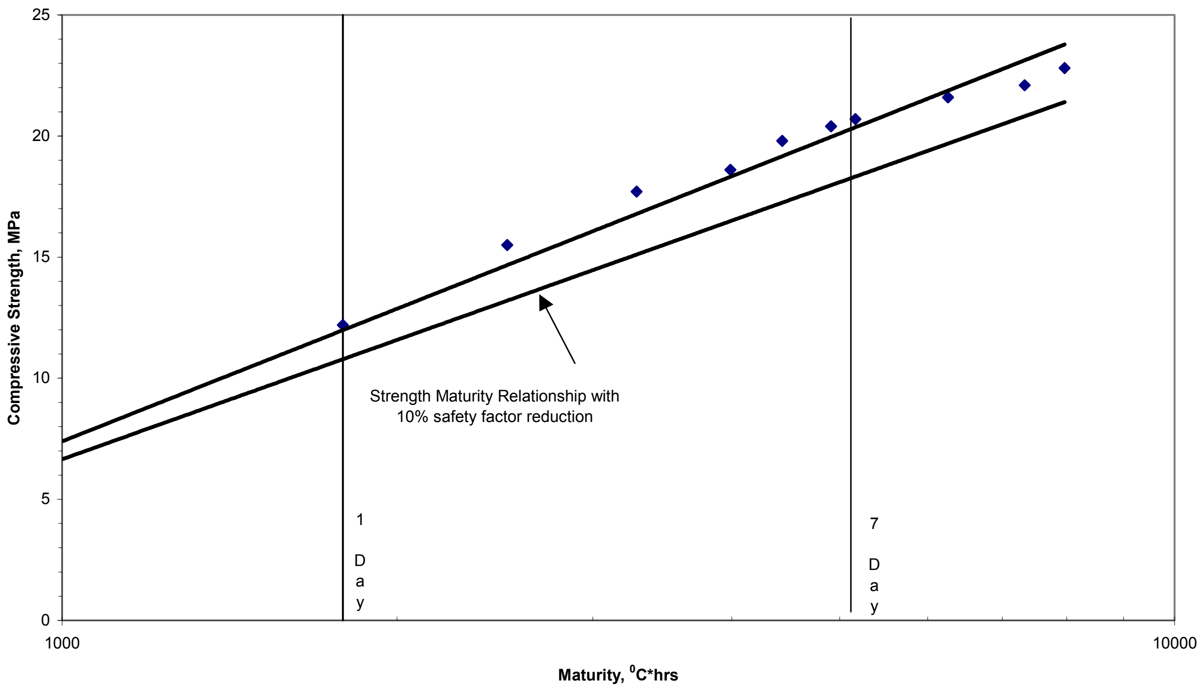


Fig. 3 Maturity Curve- Phase I

Split tensile strengths at 28 days were (Phase I Test Mix only):

Note 5: Maturity was originally developed by Plowman in the 1930s. For purposes here, it can be presented as

$$fc = A + B \log_{10} (\text{Maturity})$$

where
- fc is the compressive strength of the concrete
- Maturity = (time x temperature) {the temperature is the value over a base level at which cement hydration ceases, commonly taken as –10°C}
- A + B are constants

From a Maturity curve, one can determine the time required to achieve a particular strength (typically stripping strength) at a given in situ curing temperature.

Test	Age, Days	fsp MPa
1	28	2.9
2	28	3.1
3	90	3.4
4	90	3.2

f_{sp} values translate to about 9% of compressive strength which is normal. Failure patterns showed:

- some aggregate fracture;
- a few noticeable unsound aggregate particles;
- volcanic aggregate with mineral-filled cracks.

Photographs 8 and 9 illustrate.

4.3 Durability Properties

Property – Test at 78 Days- Phase I Test at 98 days - Phase II	Test Mix		
	Phase I Test	Phase I Supplementary	Phase II
Resistivity, ohm-cm	18,600	15,600	31,008
Permeability rating	Low	Low	Very Low
RCP, coulombs	1,150	1,210	642
Boiled, absorption, %	5.8	5.9	2.8
Volume permeable voids, %	12.8	12.9	6.4
Unit mass, wet, kg/m^3	2,335	2,325	2,371

Photograph 7 shows the structure of the Phase I Test and Supplementary Mix concretes.

The Phase II mix had a significantly higher fly ash replacement for cement – see 3.2 – and this is reflected in the improved durability properties.

4.4 Shrinkage

Refer to Fig. 4.

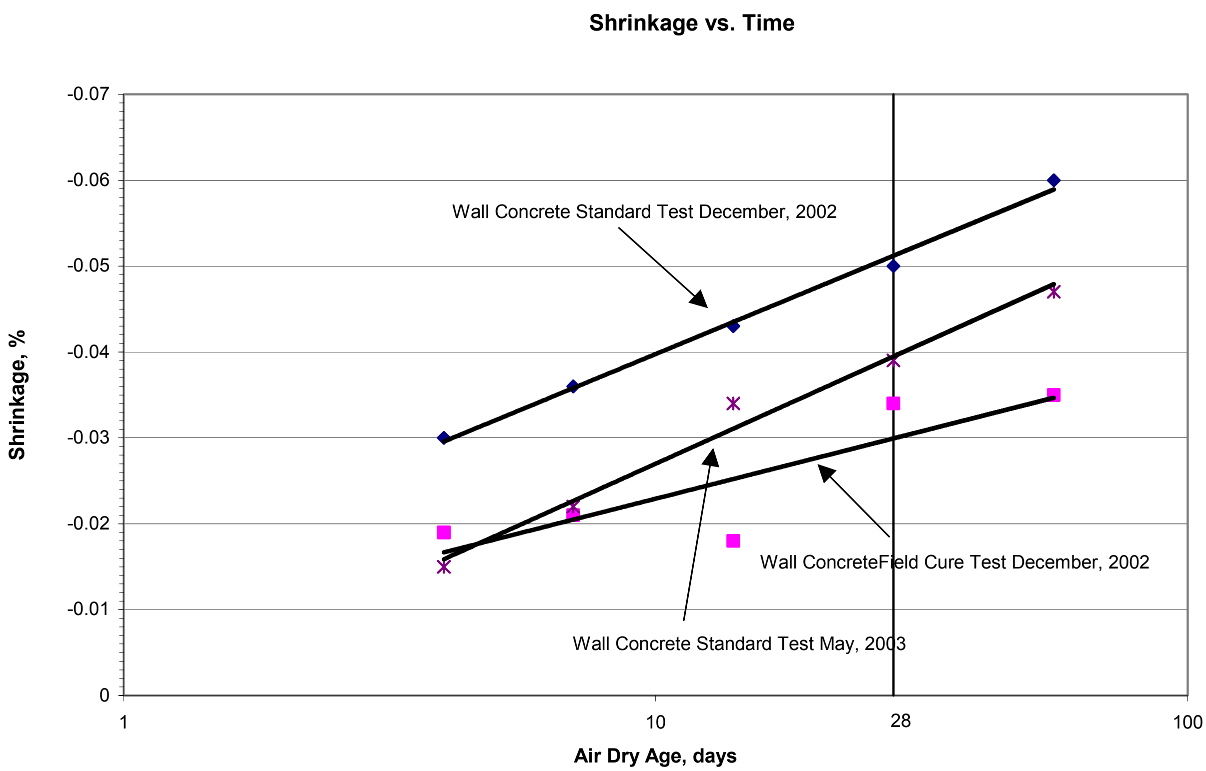
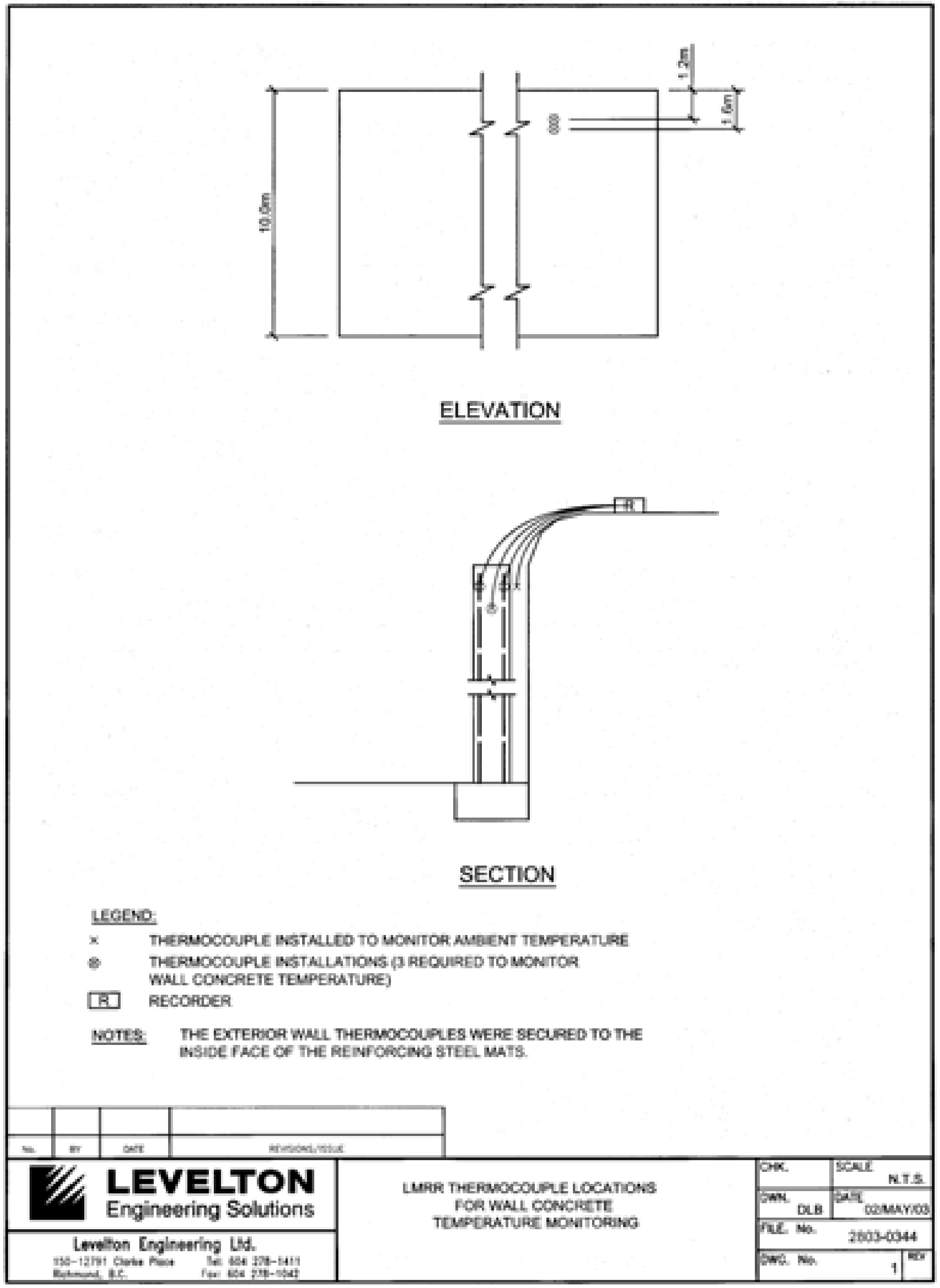


Fig. 4 Shrinkage

4.5 Temperature Profiles

Drawing 1 shows the location of thermocouples in the Phase II wall. Photograph 14 also illustrates.



Drawing 1 Location of thermocouples in the Phase II Wall

Fig. 5 shows the temperature profiles. Peak temperatures were reached in about 25 hours and returned to a stable value in about 100 hours.

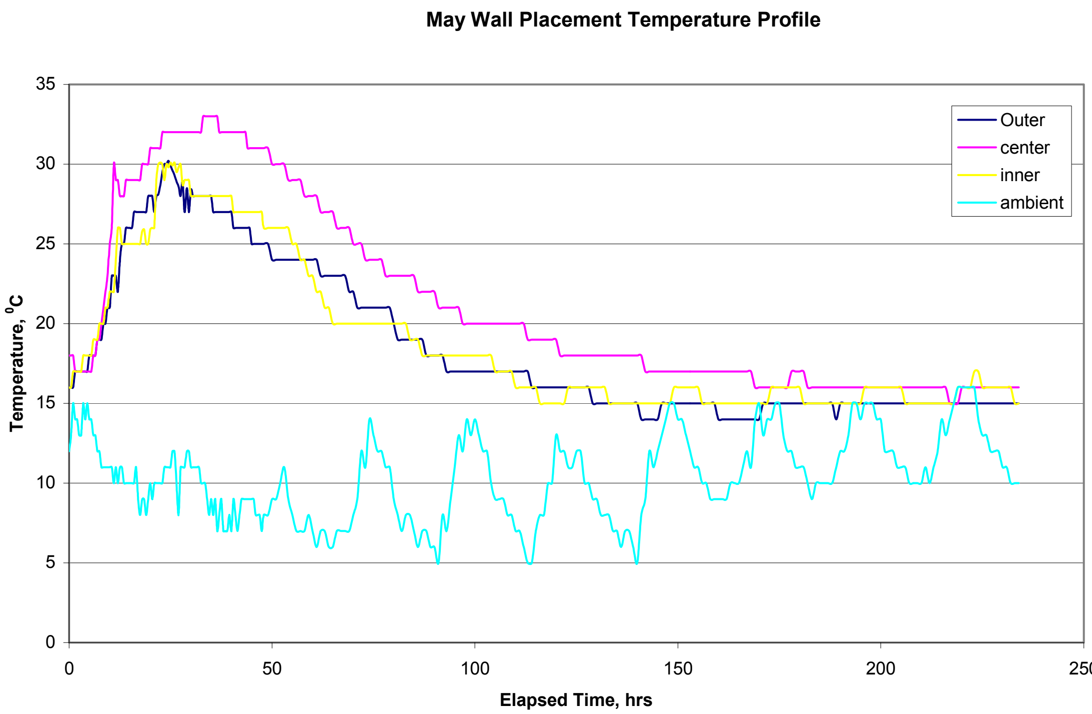


Fig. 5 In Situ Temperature Profile of Wall Concrete

5.0 DISCUSSION

5.1 General

Levelton believes that this test program provided the data necessary to satisfy the Objectives in 2.0. Inevitably, in field testing, there is some variation and anomalies in certain test results. These will be discussed below but they do not affect the overall value of the information.

5.2 Constructibilty Aspects of the LMRR Wall Concrete

As indicated in Section 3.0, the concrete showed good placing and consolidation properties. The placing crew indicated approval of its rheology. Examination of the wall concrete surfaces after form stripping showed an excellent finish, largely free of bug-holes and with good consolidation at the base (water stop zone). Project Engineers and GVRD have also judged the overall surface finish of this concrete to be excellent. Both GVRD #3 and #4 Mixes performed in a similar manner.

The concrete showed negligible amounts of bleeding. Low bleeding is expected for concrete mixtures containing higher volumes of fly ash.

Slow setting times are evident in Fig. 1. These occurred despite good initial plastic temperatures of about 17°C. Both the Phase I and II mixtures performed in a similar way; this is not surprising considering that the ambient temperature regimes at sampling were also similar. In this case there are compensating factors in Phase II vs Phase I:

- Higher exposure temperatures for the Phase II mix;
- Higher fly ash contents in Phase II;
- Higher superplasticized dosages in Phase I.

The combined effect was to produce a similar Setting Time in Phase I and II concretes.

The Initial Set of the mixtures was in the order of 11 hours and the Final Set in the order of 13-1/2 hours. Conventional concrete with the normal fly ash content in the order of 20% would be expected to have setting times significantly less with an Initial Set in the order of 9 hours at the temperatures here. The increased setting time is largely due to the higher fly ash replacement contents of this concrete although the presence of superplasticizer may have had a small contribution.

The setting time test is conducted on a small sample stored at ambient conditions which were temperatures of 9°C or less in this case. Therefore, these samples cool much more quickly than the concrete in the relatively massive wall (see Fig. 5) and the in situ setting times for the wall concrete would therefore be shorter.

5.3 Strength Properties

The Fig. 2 data shows a significant range in the 56 day strengths of the three mixtures. Reference to project quality control test results indicates that the average strength of these mixtures is typically in the 48 MPa range, while the required strength is 35 MPa.

Compressive strength values generally follow linearity as was expected.

The reason for the relatively poor performance of the Phase I Test Mix is not explained. It did achieve the required 35 MPa at 56 days but barely. It has significantly different results than others on the project; to date only two project wall concrete tests are in the 35 MPa range. Therefore, results from the Phase I Test Mix must be considered as not representative. Similarly, its age:strength curve – Fig. 2 - shows a departure from linearity which is not indicated in the other mixtures.

The split tensile results in 4.2 are normal values suggesting that the presence of the higher volumes of fly ash has no effect on the compressive:tensile strength ratio. It is the tensile strength of the concrete that controls its susceptibility to shrinkage cracking and therefore this concrete would have reasonable resistance in this regard.

Photograph 7 compares the structure of the Phase I Test and Supplementary Mixes. It is noted that there is a markedly lower coarse aggregate content in the former. In order to investigate this difference further, Levelton undertook a test to determine the coarse aggregate content of the two Mixes. Test cylinders were broken down in a muffle furnace and both the coarse aggregate weight and cement contents (based on ASTMA C1084 procedures for analysis of CaO) were determined. Results were:

Property	Phase I Test Mix	Phase I Supplementary Mix
% Coarse Aggregate	38	44
Cement Content, % total	13	16

These results must be interpreted with caution. These are based on limited sampling and, as such, may not be absolutely representative. However, they are considered relatively significant and provide a clear indication of the reason for the difference in strength. As indicated earlier, the Phase I Test Mix is not representative.

Comparing the slopes of the age:strength curves, Fig. 2 of the Phase I Supplementary and Phase II Mixes shows the flatter slope of the latter. This is a reflection of the higher fly ash content.

The Maturity curves, both those in Section 4.2 and in Appendix C, show the typical linearity expected. It was intended that the Contractor use these results to control form stripping times but they chose to use strengths obtained from cylinders stored alongside the wall sections (field cured cylinders) which is also permitted by the CSA A23.1 Standard. As indicated in Appendix C, and as experienced elsewhere by Levelton, these field cured cylinder strengths provide conservative results and the actual in situ strengths of the concrete, as judged by the Maturity curves, was somewhat higher. Practically, the results of Fig. 3 show that 10 MPa normally required for form stripping is achieved at a maturity of about 600°C hours. If a factor of safety is added to this, Fig. 3 shows that such a stripping strength is readily achieved in situ at an age less than one day.

With regard to Compressive Strength gain with time, and excluding the Phase I Test Mix for reasons indicated above, Fig. 2 shows:

- a 7:56 day strength ratio in the order of 50%;
- a 28:56 day strength ratio in the order of 83%.

These numbers are significantly lower than would be expected for conventional concrete and testify to the long term strength potential of concretes with these levels of fly ash replacement.

5.4 Durability and Service Life Potential

Tabulated results in 4.3 show concrete with an excellent resistivity (values in excess of 3000 ohm-cm are normally considered adequate for passivation of reinforcing steel corrosion) and also low permeability (RCP) values. The porosity values, such as boiled absorption, are consistent with good quality concrete which is expected to have such values less than about 6.0%.

Surprisingly, the Phase I Test and Supplementary mixes show similar results.

5.5 Shrinkage

Data in Fig. 4 shows that the 28 day (Standard) shrinkage value of the concrete is in the 0.04 to 0.05% range. In preparing the design for LMRR project, it was hoped to obtain values in the order of 0.045% and it appears that this has generally been achieved. Shrinkage values of local conventional concrete have typically been expected to be in the 0.06% to 0.07% range.

The field cured results in Fig. 4 show much lower shrinkages under that curing regime. This is consistent with published information.

5.6 In Situ Temperatures of the Wall

Information in Fig. 5 shows the expected reduction in maximum temperature when using concrete with higher volumes of fly ash replacement. The maximum temperature in the centre of the wall of about 33°C is substantially lower than what would be expected for conventional concrete with 25% fly ash; data from other projects indicates that such concrete would have values at least 10°C higher.

For 35 MPa concrete with no fly ash in these semi-mass walls, a maximum temperature in the order of 55°C would be expected.

The differential temperature between the outside or inside and the centre of this 600 mm thick wall are relatively small, in the order of 10°C.

These temperatures are monitored because they present a procedure for estimating the potential for thermal cracking. The important parameter is the difference in temperature between the ambient, which represents the exposed surfaces of the concrete, and the internal temperature. Recommendations in various ACI documents limit this differential to 20°C; Levelton has found that differentials up to 25°C can normally be accepted. In this case, the temperature differential easily meets the ACI limits.

No wall cracking has been experienced.

6.0 SUMMARY OF FINDINGS

6.1 General

1. Properties of the LMRR wall concrete are suitable for a structure designed for a 100 year Service Life. This finding is based on the high resistivity, low permeability and porosity, and low water to cementing materials ratio of this concrete.
2. This concrete had a high workability resulting in ease of placement and consolidation and the ability to produce high quality formed surfaces.
3. Constructibility problems relate to the increased setting time and slower early age strength gain as is typical for this type of concrete. However, with regard to the strength gain, by contrast with the cylinder strengths, the in situ strength of the relatively massive walls at LMRR is acceptable for form stripping on a normal schedule.
4. Hardened concrete properties reported here show:
    - Relatively low shrinkage values;
    - A potential for long term strength gain;
    - Reasonable tensile strengths that will assist in reducing the possibility of shrinkage cracking.
5. Concrete with the higher levels of fly ash replacement for cement used here had significantly lower heats of hydration.

6.2 Findings Specific to the Objectives

- EcoSmart concrete with the fly ash replacements for cement in excess of 35% had shrinkage values in the 0.04 to 0.05% range, less than those normally estimated for conventional concrete.
- This concrete did not bleed.
- Excellent workability and pumpability at slumps as low as 70 mm was achieved.
- Surface finishes free of bugholes were achieved.
- No cracks occurred in the Walls. This supported the consultant's intent.
- Setting times of this high volume fly ash concretes were at least 25% higher than conventional concrete with the normal 20% fly ash.
- This concrete performed well compared to published properties of similar concrete.
- The concrete specification used here would be appropriate for future GVRD water containing structures.
- Phase II results confirm that Phase I Test Mix data was not representative with regard to strength.

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APPENDIX A

PROJECT DETAILS AND PHOTOGRAPHS

Photograph 1
General view of site at time of Phase I. Test Wall on south side to left.

Photograph 2
Phase I Test Wall is one with forms to right.

Photograph 3
Wall forming system. Installing thermocouples and maturity gauges.

Photograph 4
Wall reinforcement.

Photograph 5
Phase I. Concrete Placement in Wall.

Photograph 6
Wall base detail showing waterstop and two curtains of dowels.

Photograph 7
Cylinders prepared for Phase I RCP test. Lower faces polished. #6273 is Test Mix; #6274 is Supplementary Mix.

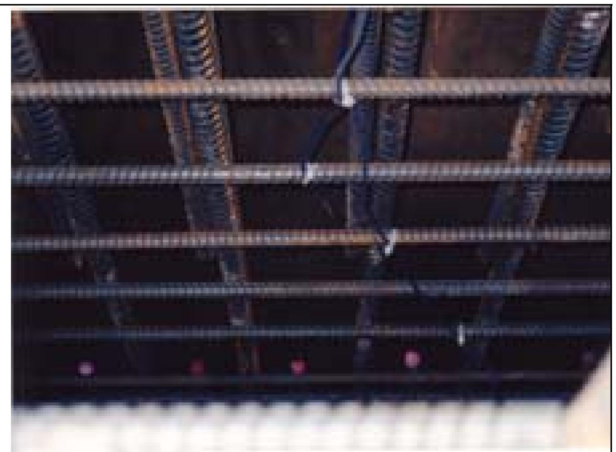
Photograph 8
Split tensile test cylinders after testing.
Right = Wet.
Left = Dry.

Photograph 9
Close-up of Photograph 8. Note some coarse aggregate fractured but most failed in paste:aggregate bond.

Photograph 10
General view of site at time of Phase II test.

Photograph 11
Test Wall for Phase II (Panel #32, north side).

Photograph 12
Top of Wall. Wire in foreground is for thermo-couples.

	
Photograph 13 Placing and vibrating concrete.	**Photograph 14** Exterior rebar met with thermocouples for temperature monitoring.

APPENDIX B

OBSERVATIONS DURING TEST WALL PLACEMENT

Field Notes

December 12, 2002

- At site to install concrete maturity probes and sample concrete for plastic properties, compression testing, maturity curve, set time, etc.
- Lafarge QC on site for start of pour. They report plastic properties to be within project specifications.
- Pour progress slow at start. Project QC at site for spot testing only. Results within project specifications. Slow pour start not communicated to ready-mix producer, four trucks batched and shipped to site. 2nd, 3rd and 4th mixer trucks approaching 120 min rejection age at start of discharge.
- 3rd truck rejected at 2 hours age as per CSA A23.1 (18.4.3.1), approximately half of load placed in forms. Truck rejected by Levelton and GVWD.
- 4th truck – last bucket in transit at rejection age.
- No more trucks to be sent for approximately 1 hour. Levelton will sample concrete at this time to ensure concrete age sufficient to complete test program.
- Wall to be heated from behind formwork. Heat applied at 11:00 – approximately 30 m^3 placed at this point.
- Lower temperature recorder started at 11:10 hours when probes encapsulated in concrete. 4 lower probes set – 1 ambient, 1 centre wall, 1 inner face, 1 outer face. Lower ambient probe set outside inner face.
- Sampling performed @ 13:30. Plastic properties within project specifications. Test samples cast following verification of plastic properties.
- Pour then proceeded a pace. Project QC on site briefly for random spot checks throughout the day.
- Levelton sampled PCC a second time from 7th truck (supplementary test). Plastic properties were within project specifications. Additional cylinders cast for companion tests to 1st set. Specimens cast at 16:00.
- Upper temperature recorder started at 18:00 hours when probes encapsulated. Configuration of probes similar to lower ones – upper ambient probe set to record temperature on heated face of wall.
- Concrete slumps throughout pour reasonably consistent. HRWR added to mix at site via truck. Air contents in the lower range. Temperatures around 16 – 17°C (winter batching procedures in use).
- Bucket transit time up to wall sufficient to allow for good vibration techniques by placing crew.
- Cast specimens left on site (protected and insulated), sample for set time and bleeding previously transported to laboratory for preparation and testing.

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APPENDIX C

PHASE II REPORT

on

MATURITY vs COMPRESSIVE STRENGTH

April 28, 2003
File: 2803-0344

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Attention: Mr. Michel de Spot, P.Eng.

PROJECT: Little Mountain Reservoir

SUBJECT: Divider Wall Maturity Tests

1.0 PROGRAM

Objective

The objective of the maturity measurement program was to support earlier removal of the forms and to confirm the agreement of maturity strength estimates and field cure cylinder test results

Approach

The program consisted of two major components: installation of the majority meters in the top portion of the wall section and casting of field cure and lab cylinders.

Three maturity meters were placed in the wall section at approximately 0.8 m below the top of the wall, in the center portion. A thermocouple was also installed on the exterior of the form to record the ambient temperature.

The meters were monitored at 2 and 3 days to advise Graham of the in situ strength of the concrete. Companion field cure cylinders were also tested at these times to compare the results of the two methods.

The field cure cylinders were stored on site at the base of the wall in an uninsulated box.

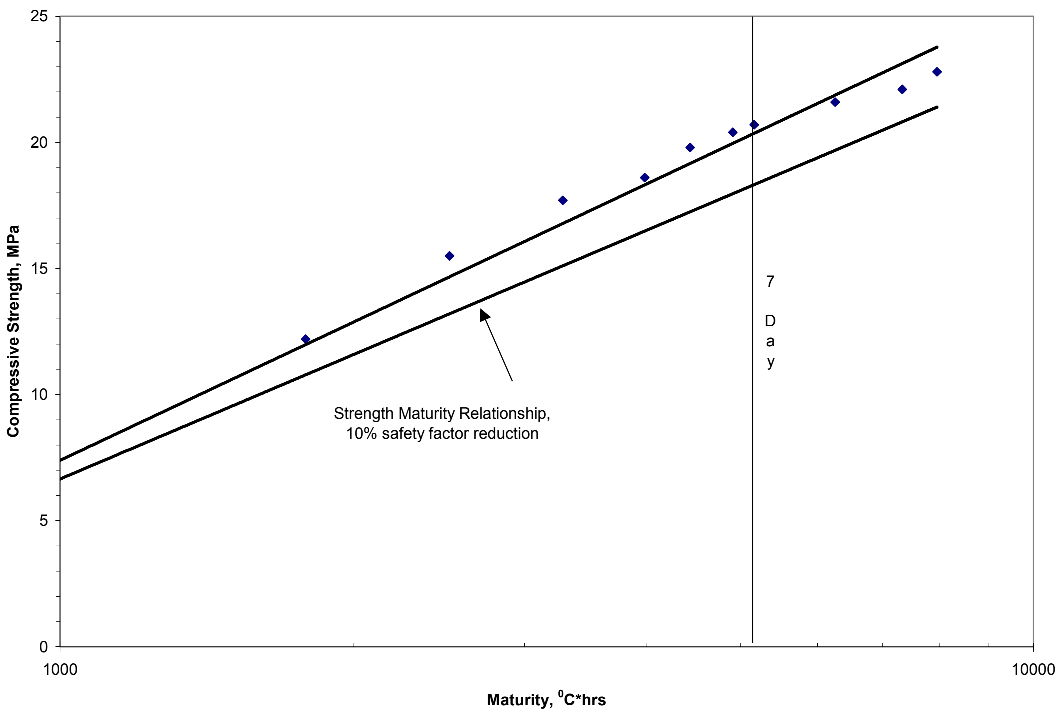
Pour Location

The concrete placement occurred on April 12, 2003. The wall section poured was interior divider wall panel 46.

Maturity Method

In order to obtain the maturity strength estimates, the maturity compressive strength relationship previously developed by Levelton for GVRD Mix 4 was utilized. A factor of safety of 10% was included in the strength estimates to account for any variations in mix proportions, water cement ratio being the one of utmost importance, refer to Figure 1: Maturity Compressive Strength Relationship. No safety factor was applied to the field cure test results.

Figure 1: Maturity Compressive Strength Relationship



2.0 SPECIFIED CONCRETE PROPERTIES

- C2 Exposure class
- 20mm maximum size aggregate
- 62% minimum coarse:fine aggregate ratio
- 35% minimum fly ash content as a percentage of total cementing materials
- 35 MPa specified compressive strength @ 56 days.

Plastic Properties as measured on April 12, 2003 test load

Slump:	70 mm
Air Content:	6.0%
Initial Concrete Temperature:	18°C
Ambient Temperature:	12°C

3.0 RESULTS

Refer to Figure 2: In Situ Strength Estimates, for the maturity strength estimates and field cure strength estimates.

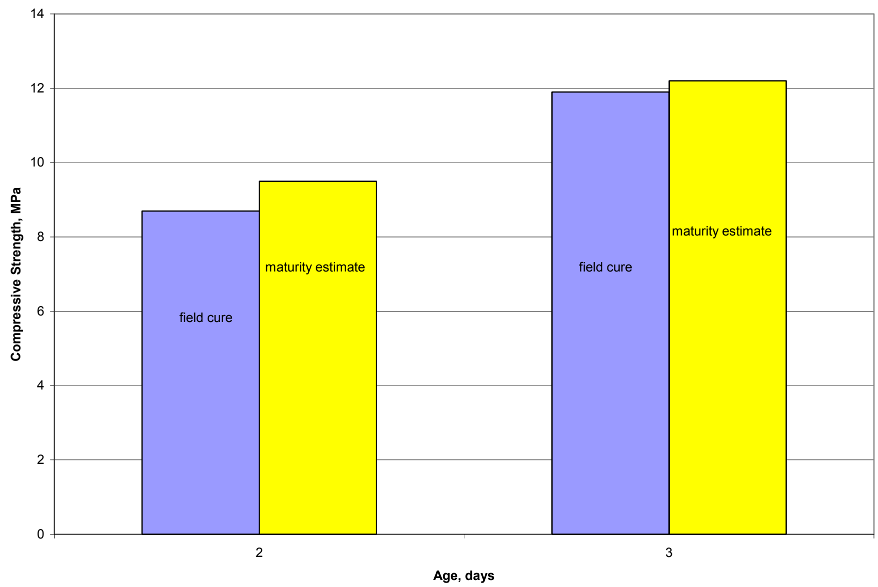


Figure 2: In Situ Strength Estimates

Figure 3 - Concrete Heat of Hydration, presents the temperature profile of the concrete during curing.

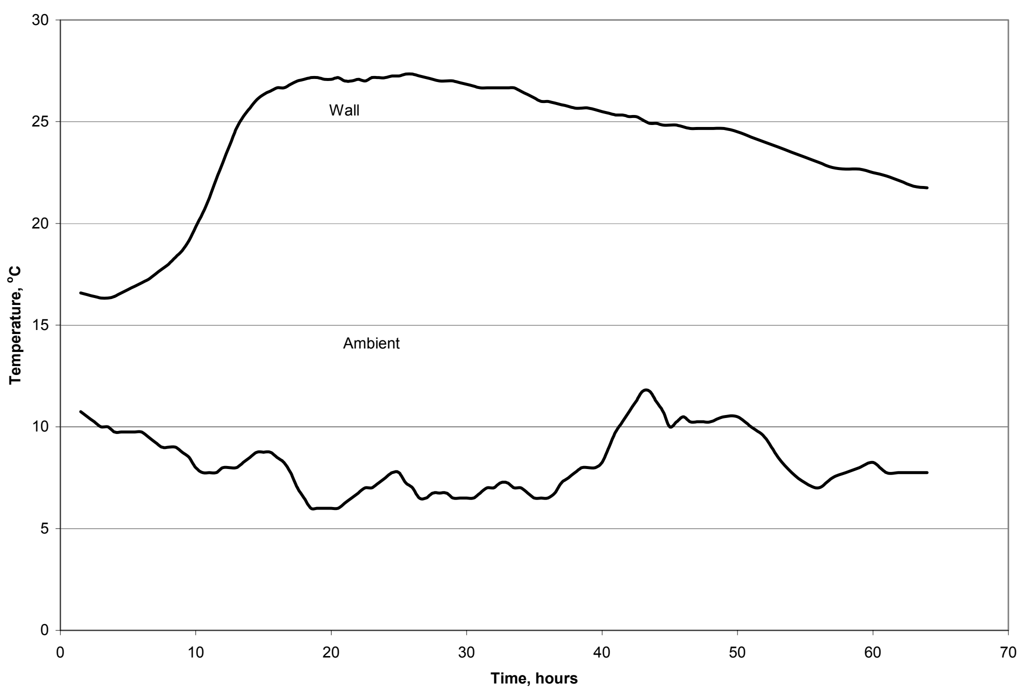


Figure 3: Concrete Heat of Hydration

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5.0 DISCUSSION

The results of the maturity and field cure cylinders test results compared very well. The measured strengths suggest that the use of field cure cylinders may be a slightly conservation method to assess the in situ strength of the concrete. It is thought that this may be due to the heat generated by the hydration reaction.

It appears that the maturity method is an appropriate method to make in situ strength estimates. However, it should be noted that variations in the mix proportions might skew the strength estimate.

1.1.1 LEVELTON ENGINEERING LTD.

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