Development and Execution of a Performance Specification for Mass Concrete in a Transit Station

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Abstract

- At the request of the owner's designer, an objective-based performance specification was developed for the mass concrete in an underground transit station.
- Later, an interpretation of the CSA concrete standard, not intended by the standards committee, led the owner to place limits that restricted the contractor's ability to meet the performance objectives.
- However, working with the contractor, the performance requirements of the concrete were still able to be achieved.

Performance Specification

- The owner and the design engineer working for the transit authority requested development of a performance specification.
- CSA A23.1 provides the Requirements for a performance specification as well as defining Roles and Responsibilities (in Table 5)

CSA A23.1 Performance Option

- The responsibilities of the owner, the supplier and the contractor are clearly defined in Table 5 with details provided in an Annex.
- For durability, CSA uses a Table of exposure classifications to set the level of performance needed: Each exposure includes minimum requirements for concrete materials, properties and curing.

Owner Responsibilities (ie. Owner's Design Authority) CSA A23.1 Table 5

a) Required structural criteria including strength at age;

b) Required durability criteria including class of exposure;

c) Additional criteria for durability, volume stability, architectural requirements, sustainability, and any additional Owner performance, pre-qualification or verification criteria;

d) Quality management requirements;

e) Whether the concrete supplier shall meet certification requirements of concrete industry certification programs; and

f) Any other properties they may be required to meet the Owner's performance requirements

Contractor Responsibilities
CSA A23.1 Table 5

a) Work with the supplier to establish the concrete mixture properties to meet performance criteria for plastic and hardened concrete, considering the contractor’s criteria for construction and placement and the Owner’s performance criteria;

b) submit documentation demonstrating the Owner’s prequalification performance requirements have been met; and

c) prepare and implement a quality control plan to ensure that the Owner’s performance criteria will be met and submit documentation demonstrating the Owner’s performance requirements have been met.

CSA Supplier Responsibilities CSA A23.1 Table 5

a) Certify that the plant, equipment, and all materials to be used in the concrete comply with the requirements of this Standard;

b) certify that the mixture design satisfies the requirements of this standard;

c) certify that production and delivery of concrete will meet the requirements of this standard;

d) certify that the concrete complies with the performance criteria specified

CSA Supplier Responsibilities (cont’d)

e) Prepare and implement a quality control plan to ensure that the Owner’s and contractor’s performance requirements are met if required;

f) Provide documentation verifying that the concrete supplier meets industry certification requirements, if specified; and

g) At the request of the Owner, submit documentation to the satisfaction of the Owner demonstrating that the proposed mixture design will achieve the required strength, durability, and performance requirements.

CSA Annex J: Contractor & Concrete Supplier Joint Responsibilities

"Since in a typical construction project the custody of the concrete transfers from the supplier to the contractor while in its plastic state, a high degree of coordination is required between supplier and contractor to ensure that the final product meets the performance criteria and that the quality control processes are compatible and demonstrate compliance."

The Project

- A new underground subway station
- Reinforced mass concrete base slab and walls (2.1m thick slab and 1.0m thick walls)
- Below the water table
- Will be exposed to freezing temperatures and to tracked-in de-icers, therefore a CSA C-1 exposure (= ACI C-3) as well as moderate sulfates (CSA S-3 (= ACI S-1) exposure)

The Owner’s Objectives

- For extended service life in a chloride, frost (inner faces) and sulfate (outer faces) exposure.
- Prevent leakage through mass concrete
  - Minimise thermal and drying shrinkage cracking
  - Watertight joints

Section 03 30 13

CAST-IN-PLACE MASS CONCRETE

1.1.2. The specification covers ‘mass’ cast-in place concrete. **Mass cast-in-place concrete is** any section thickness of a single concrete pour that is more than 1000 mm thick for formed elements, 500 mm slab-on-grade, or 500 mm wall poured against adjacent wall or excavation. Thinner sections would be considered ‘normal’ concrete and is covered in section 03 30 00.

Caveat: the following slides are from a draft of the performance specification and may not be identical to the final version used for construction.

1.2 Mass Concrete

1.2.2.The Owner requires a strong, highly impermeable, freeze-thaw resistant concrete with minimal shrinkage (crack widths not to exceed 0.3 mm) and control of thermal gradients. Since the Performance option has been chosen and to facilitate an understanding of the Owner's requirements a mandatory pre-bid meeting will be held.

1.2.3. Where there is any conflict between this specification and CAN/CSA A23.1/A23.2 the requirements of this specification shall apply.

(this becomes important later)

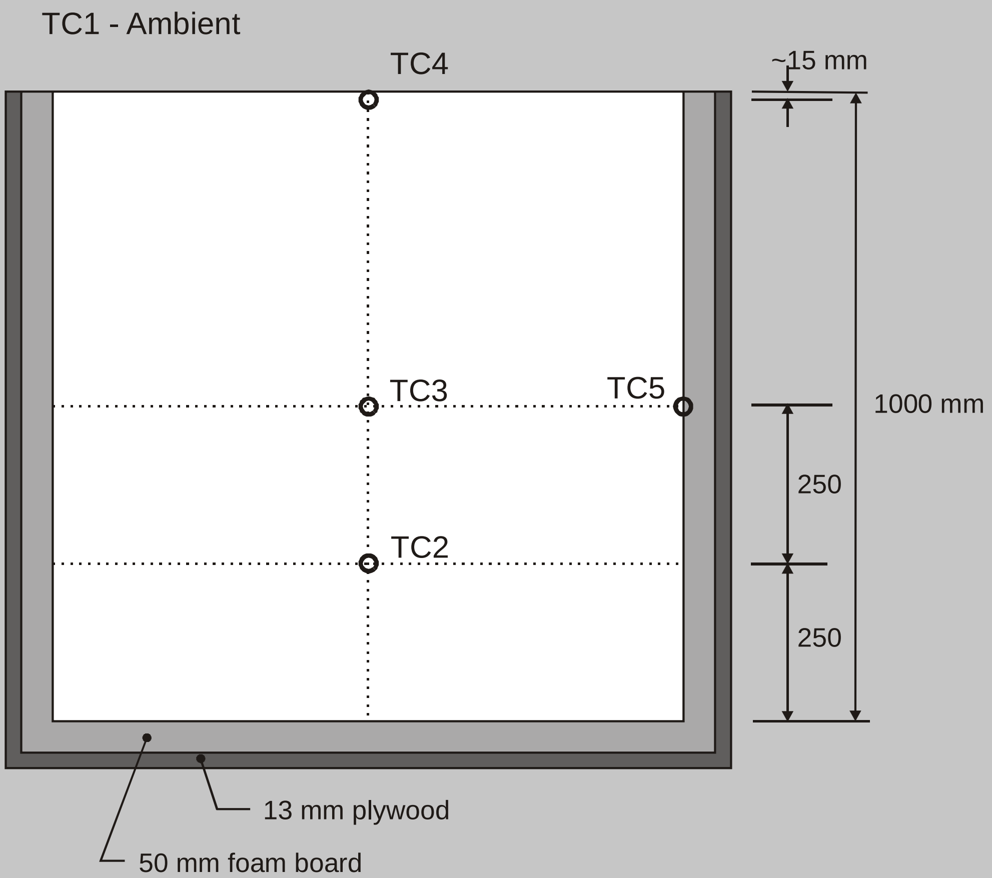
1.3 Submittals

1.3.1 Submit Quality Assurance/Quality Control program in accordance with section 01 40 00. Quality program shall include schedule and procedure for trial mixes, monolith tests, mix submissions, field testing and monitoring program, procedure for adjusting mix due to site variability, and Contractor means and methods as outlined in this specification. The Quality Assurance/Quality Control Program will ensure that the Owner's performance criteria will be met and submit documentation demonstrating the Owner's performance requirements have been met.

1.3.2 **Allow for sufficient time within the schedule for monolith construction**, curing, testing with analysis and reporting of data. Also allow within the schedule, sufficient time for additional monolith tests should additional batch trials be necessary.

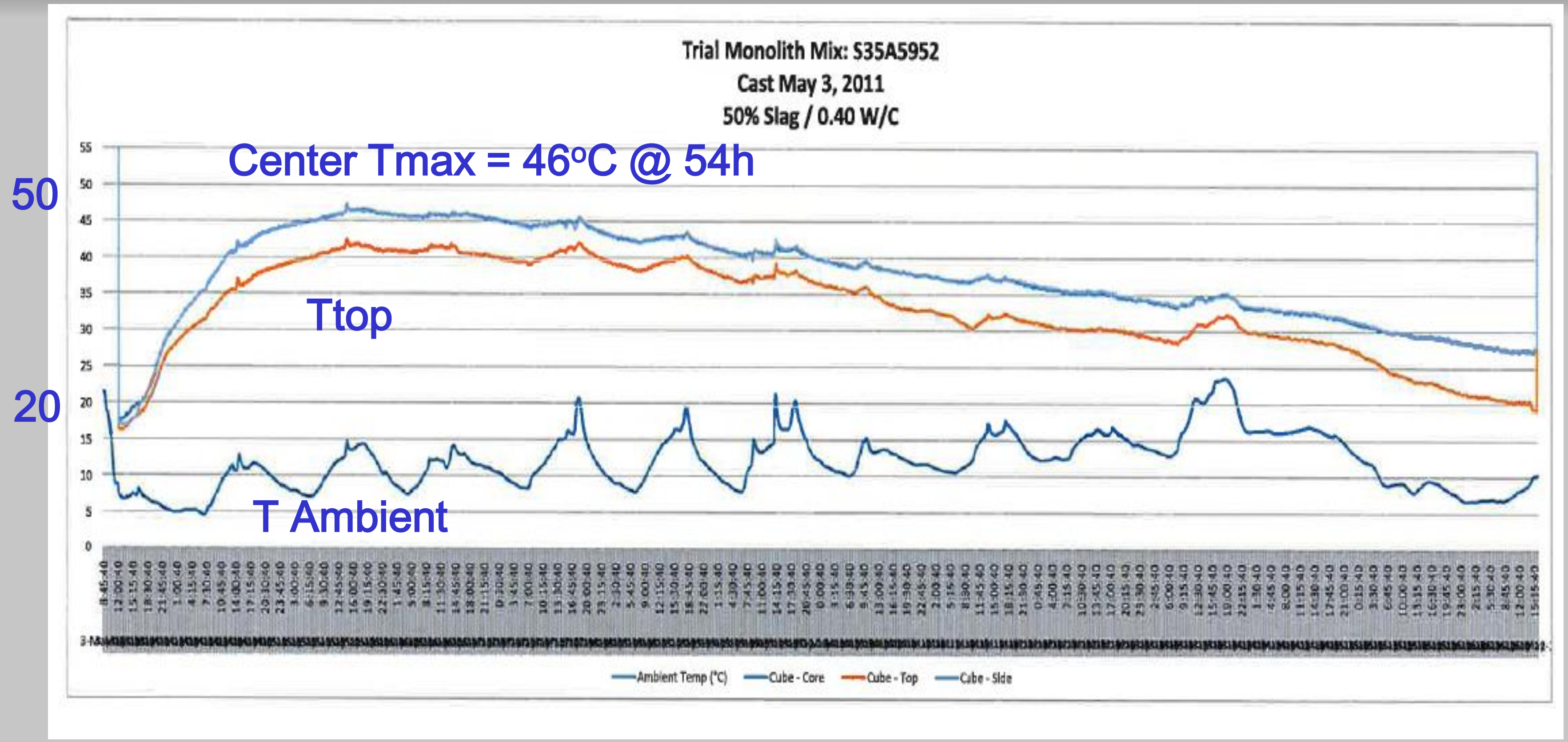
Pre-Qualification Tests on 1 m^3 Monolith for Mass Concrete (results provided to owner & owner can also take cores)

Concrete Suppliers must pre-qualify their Proposed Mixes using Monolith Tests and **perform tests on cores from block**



Bickley & Hooton

50% Slag. w/cm = 0.40. 6% Air Monolith--14 day Temps.



Tbatched = 17C, T delivered = 22C, Time to form removal = 242h

1.4.1 QC Plan

Submit the Quality Control plan for the Owner's Representative review at least 8 weeks prior to the proposed trial monolith testing. Include the following in the Quality Control plan and any additional requirements, materials, or testing in order to meet and demonstrate the performance requirements have been met to the Owner.

1. Uniform and consistent concrete finishing.
2. Protection of Fresh concrete, including severe drying protection measures
3. Cold weather protection.
4. Hot weather protection.
5. Concrete curing
6. Concrete placing. including pour sizes, methods and sequence of pouring
7. Methods of consolidation
8. Duration and methods of curing

1.4.1 QC Plan

9. Procedures to monitor and control maximum concrete temperature at time of placement, temperature gradient, and maximum curing temperature including:

   1. Thermocouple sensor types and locations
   2. Temperature recording systems, frequency and duration
   3. Thermocouple sensor types and locations
   4. Field adjustments for concrete exceeding allowable range
   5. Seasonal adjustments
   6. Mechanical cooling systems (if proposed as part of plan)

1.4.1 QC Plan

10. Proposed Testing Program, including type, frequency and duration of tests for trial, monolith and field testing; correlation between fresh concrete tests such as slump and the final concrete properties

11. Monolith Requirements, including:

    1. Proposed mix determined by laboratory tests

    2. A dimensioned drawing of the monolith showing the location of all thermocouples and the proposed locations at which test specimens shall be obtained at various ages.

    12. A dimensioned drawing showing the field location of all thermocouples and the proposed locations at which test specimens shall be obtained at various ages.

13. Crack repair procedure.

QA Requirements

1. The Contractor shall carry out all necessary preconstruction testing of materials and keep a comprehensive record of all test results.
2. Preconstruction tests shall include a suite of Identity Tests that enable confirmation on site that the mix being delivered is the mix proven to meet the specification requirements.
3. In addition to all laboratory testing the following monolith tests shall be made. The casting and testing of concrete from the monolith shall be carried out in the presence of the Owner’s Representative.
4. The preconstruction testing of concrete and concrete making materials and all testing of concrete during construction shall be done by suitably certified testing laboratories. Details of the laboratories that will be used shall be included in the bid.
5. Do not place concrete prior to written approval of Quality Assurance/ Quality Control program.

QC Testing During Construction

1. **Quality Control and all related testing during construction shall be the sole responsibility of the Contractor** and shall be carried out **in accordance with a Quality Assurance/Quality Control plan submitted and approved** in accordance with section 01 40 00.

2. All sampling and testing shall be carried out strictly in accordance with the appropriate standard by CSA certified laboratories equipped to carry out the specified tests. The name and relevant details of the testing laboratory the Contractor and Subcontractor (concrete supplier) propose to use shall be submitted to the Owner for approval.

3. **All the specified properties of the concrete shall be confirmed during construction.**

QC Testing During Construction

4. The Subcontractor (concrete supplier) shall report all non-compliances to fresh and hardened concrete samples to the Contractor and Owner immediately after they occur together with details of the remedial action taken.

5. Concrete pours will be instrumented for temperature measurements, Refer to requirements for temperature monitoring, recording and analysis.

6. All test data shall be made available to the Owner's Representative.

7. Should the Owner wish to carry out any additional testing during construction the Contractor will provide all necessary access and assistance.

Strength

Compressive strength **in-place**

29.8 MPa (0.85x 35 MPa) at 91 days;

longer time to reach specified strength allows the use of a mix with significant percentages of supplementary cementing materials resulting in less heat generation

Hardened Air Content

Required minimum in-place air content 3%,

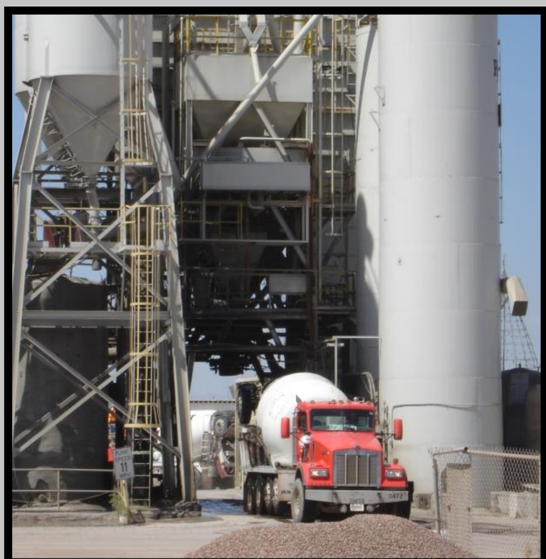
Required average maximum in-place air-void spacing factor: 0.230 μm with no single value exceeding 260 μm.

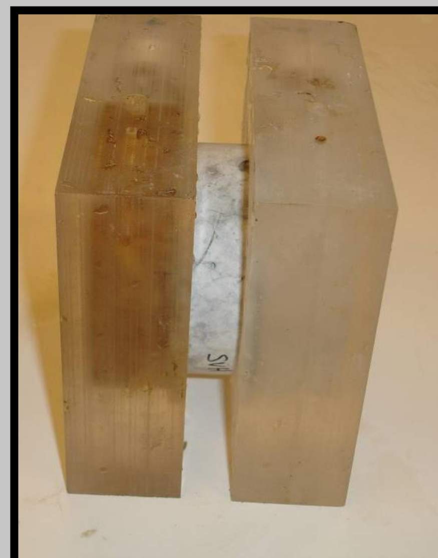
These criteria have been found to be adequate for freeze-thaw resistance.

Chloride Penetration Resistance

Required maximum permeability index of 1500 coulombs at 56 days using ASTM C1202 as indicated in preconstruction tests by the following maximum diffusion coefficient using test procedure ASTM C1556 after 28 days of age: 3.0×10^{-12} m^2/s

Specified values should vary with point of evaluation (Permeability Index)





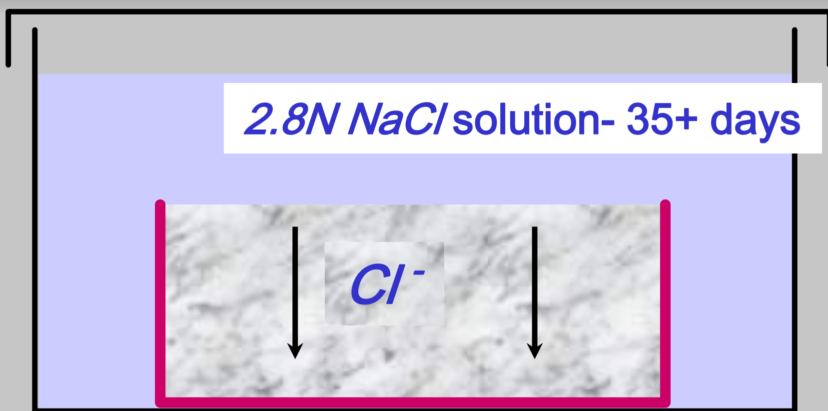
(Target ~1250 Coulombs)

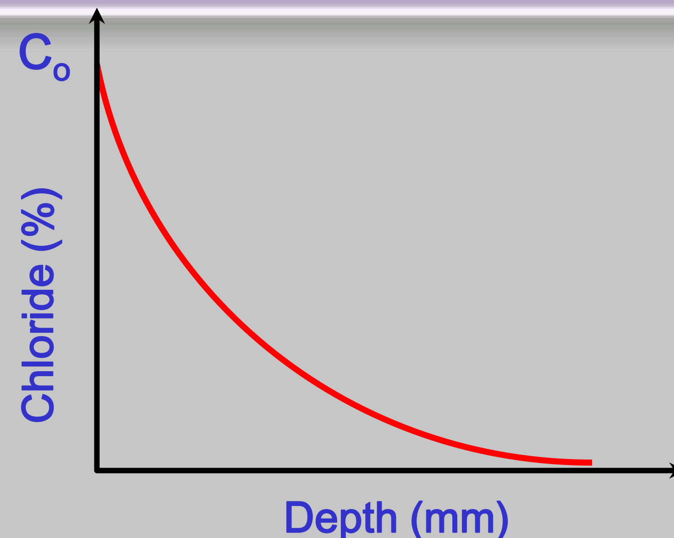
Specified 1500 Coulombs

In-place Average <1500 and no single value >1750 Coulombs

From Canadian CSA A23.1 for C-1 Exposure

Chloride Bulk Diffusion Test (Da)
ASTM C1556 / NT Build 443

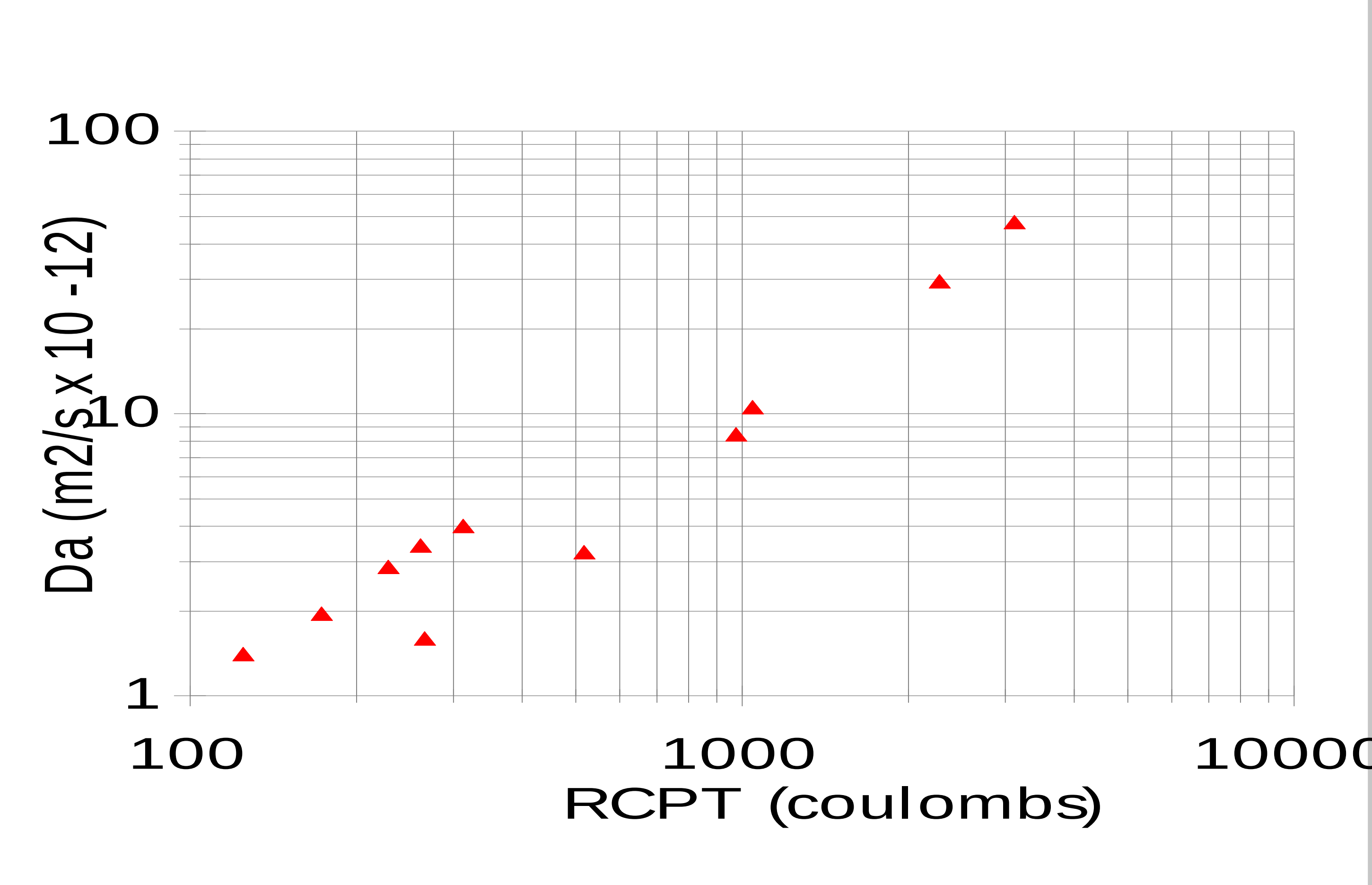




$$\frac{C_x}{C_0} = 1 - erf\left(\frac{x}{2\sqrt{D_a \cdot t}}\right)$$

C_o and D_a are found by curve fitting

Relationship between D_a and RCPT



Titherington and Hooton 2004

Drying Shrinkage

Maximum shrinkage of concrete prisms determined after 7 days moist curing followed by 28 days of drying: 0.040%

Essentially ASTM C157

Temperature Max. & Gradients

The maximum temperature of the concrete in place shall not exceed 55^{o} C with a maximum allowable temperature gradient in any element of 20^{o}C.

In addition, the removal of forms shall not take place until the temperature gradient between the surface of the concrete and ambient complies with Table 21 of CSA A23.1.

Max. Temp. Gradients for From Removal (CSA A23.1)

Table 21
Maximum permissible temperature differential between concrete surface and ambient to minimize cracking — Wind up to 25 km/h
(See Clauses 7.4.1.3 and 7.4.1.5.3.4 and Figure D.2.)

	Maximum permissible temperature differential, °C				
	Length-to-height ratio of structural elements*				
Thickness of concrete, m	0†	3	5	7	20 or more
< 0.3	29	22	19	17	12
0.6	22	18	16	15	12
0.9	18	16	15	14	12
1.2	17	15	14	13	12
> 1.5	16	14	13	13	12

General Requirements

- *Meeting these criteria requires the use of concrete mix designs that generate minimal heat of hydration.*
- *Typically these mixes are achieved using high-volume cement replacement with supplementary cementing materials.*
- *Also the controls of mixing and delivery temperatures need to be considered in the context of the time of the year that the concrete will be placed.*
- *The use of insulated formwork and extended times prior to formwork removal may be required.*

Problems

- The draft performance spec got sent out to the different design firms for each transit station.
- These other firms were not involved in the development, so they started adding additional requirements.
- Also the owner decided on an unitended interpretation of CSA A23.1 requirements for HVSCM concretes, that made it difficult to make mass concrete that would comply with the performance objectives (ie. no cracking).
- So the Contractor at one station who was ready to meet the performance spec. asked for help in dealing with the modified spec.

HVSCM on Site

- CSA A23.1 says HVSCM-1 concretes (> 50% slag) in severe exposures have to be designed with 0.05 lower w/cm. (This was intended for thin elements with limited curing).
- The owner said this also had to apply for this mass concrete, which meant lowering w/cm to 0.35 or keeping slag < 50%.
- **Either of these measures will increase the risk of cracking----and not meeting the original objective.**
- We worked with the contractor, but could not change the owner' mind, so the contractor had to try and design a concrete that would meet.

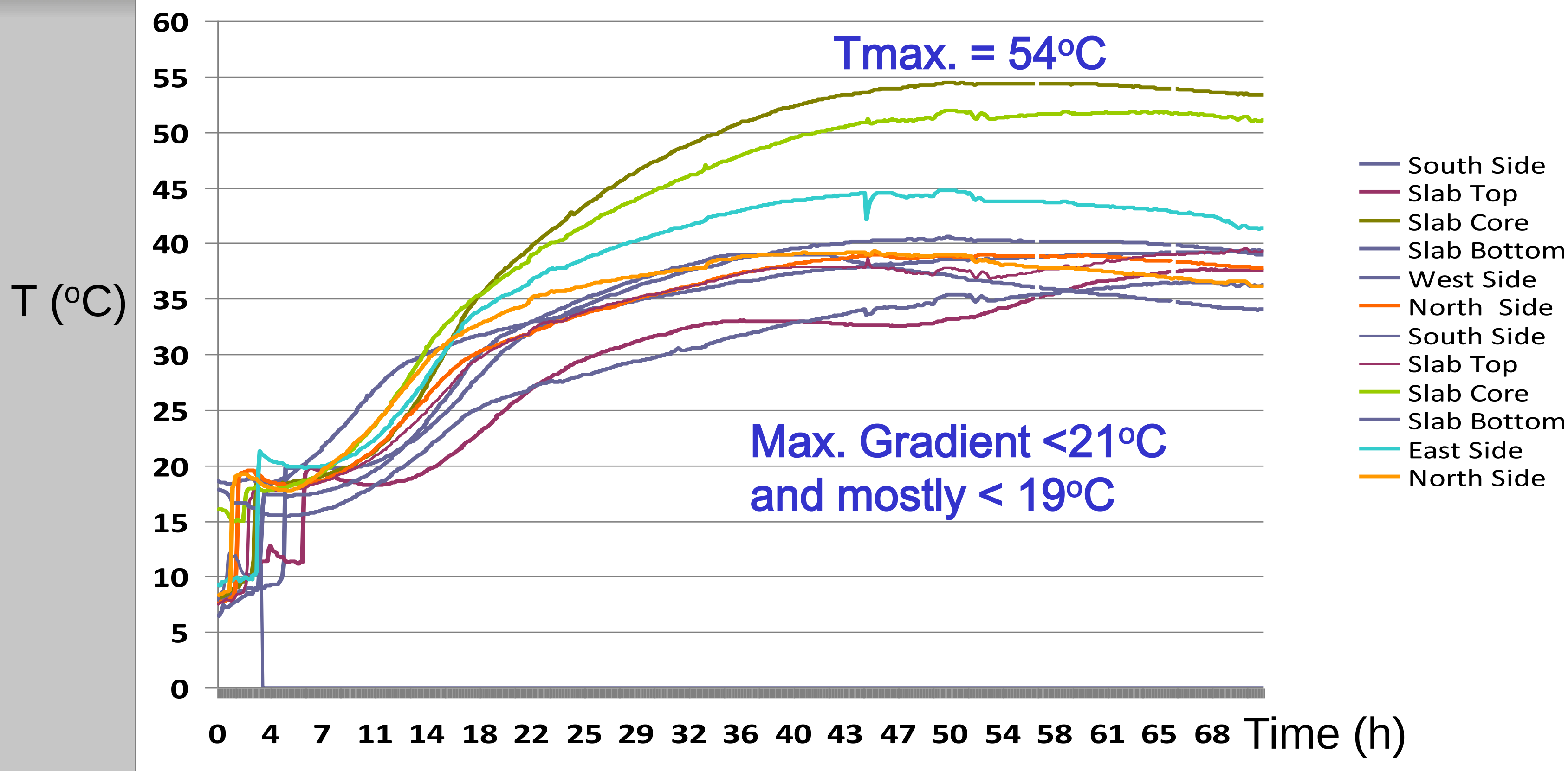
Nov. 26, 2011 mass concrete base slab for Subway Station, Toronto

- 1200 m^3 coming from 2 plants
- 2 concrete pumps (and one spare) with 4 trucks feeding the pumps at a time (140-150 m^3/h).
- CSA C-1 mix (w/cm < 0.40, permeability index <1500 @ 56d coulombs) with 125-160mm slump and 5-7% air.
- **49% slag (not 50%!)—so not HVSCM-1**
- 40mm aggregate to help reduce heat.
- Top re-bars at 150 mm (6 in.) spacing.
- T.max. = 55^{o}C with max. gradient = 20^{o}C.
- Base slab = 2.2m (7.1 ft) thick, later covered by 300mm (12 in.) topping to set track inverts.

Slab Placement at Partially Excavated Subway Station

Placing and vibrating

Slab Temperature Rise in 1st 72h



The in-place limits were met in cool weather placement and matched the prequalification tests using the monolith trials.

Slump and air tested on each truck, then concrete taken to lab to cast test specimens

Every 10th truck samples placed in coolers and transported to lab on site

Summary

- An objective-based performance specification was developed for mass concrete.
- The use of monolith blocks for prequalification showed that the thermal requirements could be met.
- Roles and responsibilities are defined.
- Conflicts between the specific performance specification and CSA A23.1 need to be resolved with the Owner in advance.