An Innovative Process for Winter Construction of Concrete Sidewalks
The City of Calgary

Bozena Czarnecki, Ph.D., P.Eng.
Principal Specialist, Engineering Practice
Tetra Tech EBA Inc.

Joe Chyc-Cies, P.Eng.
Materials and Research Engineer, Construction, Roads
The City of Calgary

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ABSTRACT

In 2012, after negotiations with multiple stakeholders, the revised City of Calgary (The City) Standard Specifications for Roads Construction were implemented. The summer construction season in Calgary is short and winter conditions can occur as early as September. The specifications for Concrete Sidewalk, Curb and Gutter define cold weather air temperature and the curing requirements for the off-season concrete in accordance with CSA A23.1. The Urban Development Institute of Calgary proposed lower temperature limits for winter construction combined with limited concrete protection to extend the construction season for concrete works. However, The City is reluctant to relax the winter concreting and curing regime as the value of the backlog of concrete sidewalk repairs and replacement is high, and increasing, with many failures attributed to off-season concrete construction practices.

The City commissioned Tetra Tech EBA Inc. (EBA) to undertake a comprehensive review of sidewalk construction specifications and the requirements for winter curing by other municipalities across Canada, and, to develop a cold weather placing and testing protocol. The guidelines for concrete placement, the testing protocol for laboratory and field testing, and the acceptance criteria were developed. In October and November of 2013, a comprehensive research program was conducted and the results were compiled in consideration for relaxing the existing specifications for concrete sidewalk construction.

This paper describes in detail the process and the data analysis. The technical aspects and the impact of the potential changes to the winter curing construction practices on the sustainable quality concrete surface works are discussed.

INTRODUCTION

In 2009 EBA, A Tetra Tech Company (EBA) was commissioned by The City to undertake a comprehensive review or The City's standard specifications for road construction. The process that incorporated input from a wide spectrum of stakeholders, including contracting and development industries and The City's technical and administrative groups, was developed (Johnston, et al. 2012) and consensus specifications were issued in 2012. In the fall of 2013, the Calgary Chapter of the Urban Development Institute (UDI) raised concerns about shortening the concrete sidewalks construction season if the requirements of the 2012 specifications are followed. A comprehensive research study was developed to verify if deviations from the standard specifications are possible for the Calgary climate.

This paper describes the process to develop a testing program that would form the basis for the possible relaxation of The City's specifications and existing codes for Calgary climatic conditions.

CURRENT SPECIFICATIONS – A REVIEW

The American Concrete Institute provides a Guide to Cold Weather Concreting (ACI 306R-10). By ACI definition, *cold weather exists when the air temperature has fallen to, or is expected to fall below 4°C during the protection period. The protection period is defined as the time required to prevent concrete from being affected by exposure to cold weather. Concrete placed during cold weather will develop sufficient strength and durability to satisfy the intended service requirements when it is properly produced, placed, and protected*. ACI also provides a commentary limiting rapid temperature changes before the concrete has developed sufficient strength to withstand induced thermal stresses and that satisfactory strength for 28-day standard-cured cylinders is of no consequence if the structure is damaged by freezing and dehydration.

Canadian Standards Association provides the following definition in CSA A23.1-14, Concrete materials and methods of concrete construction [(1)]: *When there is a probability of the air temperature falling below 5°C within 24 h of placing (as forecast by the nearest meteorological office), all materials and equipment needed for adequate protection and curing shall be on hand and ready for use before concrete placement is started. Concrete shall not be placed on or against any surface that will lower the temperature of concrete below 10°C.* In addition, during cold weather an adequate protection of the concrete shall be provided that will maintain the concrete temperature at a minimum of 10°C for the duration of the required curing period as defined in Table 19, Allowable curing regimes. The curing time for sidewalks is 7 d at ≥ 10°C and for the time necessary to attain 70% of the specified strength. The maximum permissible temperature differential between the concrete surface and ambient temperature to minimize cracking is also specified in CSA A23.1, Table 20, and is 12°C for sidewalks.

The City's Roads Construction 2012 Standard Specifications contain the following seasonal requirements for concrete placed between September 30 and the subsequent May 1; *the minimum allowable concrete compressive strength shall be attained in seven days, and, the contractor shall adequately cover and protect the freshly placed concrete and cure for a minimum of seven days above 10°C as per CSA A23.1-09, Table 20, Additional curing requirements – Curing Type 2*.

In January 2013 UDI issued a memo that, in their opinion, the curing period could be reduced from seven days to achieve the 70% compressive strength. The memo had no reference to concrete durability and the temperature differentials to minimize cracking. The proposed protocol included a removal of frozen soil prior to pouring concrete, use of a concrete mix that would achieve the 28 day compressive strength at seven days, cast field cure cylinders and place next to the cast element, and, remove protection once the concrete has achieved 70% of the specified compressive strength.

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[1] Note (1) the 2012 Roads Construction Standard Specifications refer to 2009 edition of CSA A23.1. In this paper the 2014 edition of CSA A23.1 is quoted. While there are some changes to the numbering of the tables and sections in the current CSA A23.1 edition, the curing requirements and the permissible temperature differentials remained unchanged.

THE CITY OF CALGARY PERSPECTIVE

In 2008, The City engaged Volk Consulting to study the subdivision sidewalks, curbs and gutters and to comment on the current specifications, inspections and replacement practices. Sample data from the 2007 FAC (Final Acceptance Certificate) inspections of the 6200 residential lots indicated that 30% to 35% of sidewalks and 25% of curbs and gutters were replaced and 10% of concrete was mud-jacked. That was translated to 41 km of replacement, 12 km of mud jacking and 8.2 million of replacement/repair costs. The two main causes of deficiencies are third party damage and settlement, both resulting in cracking. While concrete cracking due to winter construction was not addressed, the report recommended more stringent compaction testing and limit winter backfilling with frozen material. The conclusions of the report provided the following comments.

- The City of Calgary has the weakest concrete specifications of any other cities surveyed.
- Other cities have one-third or less replacement compared to Calgary.
- Other cities that have less % replacement.
    - Require granular base and thicker concrete.
    - Little tolerance for deficiencies.
    - Inspection specifications are more stringent.

It should be noted that the study analyzed the data points at the FAC stage only but there is a high level of deficiencies of the sidewalks, curbs and gutters replaced by the developers at FAC and therefore owned by The City. The City has a multi-million dollar sidewalk replacement backlog and it is growing. Any relaxation of the existing codes and specifications for placing concrete in winter carries a high risk of increasing an already high replacement rate of concrete sidewalks, curbs and gutters.

DEVELOPMENT OF TESTING PROGRAM FOR THE PILOT STUDY

The initial testing protocol proposed by UDI was amended by EBA and was intended for the conditions where the minimum specified ambient temperature of 10°C would not be attained through the seven-day period following the concrete pour as per City of Calgary Standard Road Construction Specifications and CSA A23.1, Section 7.4.1.5, Cold weather concreting. The testing protocol was as follows.

At least 30 full tests were recommended to evaluate the effectiveness of the UDI proposed procedure for cold weather concrete placement; five tests for the placing temperature range of 0°C to -5°C, 15 tests in the range of -5°C to -15°C, and 10 tests in the range of temperatures below -15°C.

The testing frequency has been modified to require three tests per week for the next five weeks in an attempt to simplify the testing schedule while providing enough data points to evaluate all temperature ranges.

1. The Developer/Contractor shall notify The City and the Consultant 24 hours prior to intended concrete placement.

2. The Developer/Contractor shall remove all frozen soil prior to placing concrete.
3. The Consultant will check the temperature of the base soil by pounding a pin and inserting a temperature probe. The frost penetration below the replaced soil, if any, shall also be determined.
4. The Consultant shall provide continuous temperature monitoring (every 15 minutes) using temperature probes, one at or near to the concrete surface and one close to mid-height of the concrete section. The temperature shall be monitored for a minimum of seven days after concrete placement. The intent of monitoring the temperature history of the concrete is to aid in determination of concrete maturity. The concrete temperature data was not considered for determining concrete acceptance in the absence of field identified concerns but for comparison with the CSA permissible temperatures to minimize cracking.
5. The Consultant shall test for plastic concrete properties and compressive strength testing for cylinders cured in laboratory conditions.
6. In addition to the standard concrete testing requirements, the Consultant shall cast a set of three field cured cylinders to be tested for compressive strength at the time of protective tarps removal to confirm that the specified 70% of the design strength was achieved on the field cured cylinders.
7. At the time of the tarp removal from the sidewalk/curb/gutter, a total of three 100 mm diameter cores will be extracted and tested in accordance with CSA A23.2-14C. The cores shall be stored at ambient air temperature until being brought into the testing laboratory. Testing of cores shall commence no later than three hours after being brought to the testing laboratory (i.e., for sufficient time for the cores to reach a nominal temperature of at least 10°C). The conditioning requirements of CSA A23.2-14C, Sections 5.3.1 and 5.3.2, shall not apply. The provisions of CSA A23.1-09, Section 4.4.6.6.2, for cores drilled from a structure, shall not apply.

RESULTS OF THE STUDY

A total of nine tests were completed in the testing program between October and November 2013. The number of tests fell short of the testing recommended for the statistical significance and not all temperature ranges were covered, specifically, there were no tests for below -15°C range. The results of the study are summarized in Table 1.

Table 1. Summary of Test Data										
Test #	**Date and Time**	**Ground Condition**	**Protective Cover**	**Compressive Strength (MPa)**				**Temperature Data (°C)**		
				Lab Cure (7d)	Lab Cure (28d)	Field Cure (age)	Cores (age)	Ambient Air at Cast[1]	Min. Air within 24hr[3]	Min. Internal within 24hr[4]
1	22-Oct 09:45	Not frozen 5°C	Felt fabric	31.5	42.2	23.2 (3d)	24.1 (3d)	5.0	4.8	--
2	29-Oct 11:00	On ACP Not frozen	Felt fabric with plastic	32.3	42.2	24.9 (6d)	**22.3**[2] (6d)	-5.0	-6.0	5.0
3	1-Nov 09:30	Not frozen 11°C	Felt fabric with plastic	29.6	37.7	22.4 (6d)	**16.9** (6d)	1.0	-2.0	12.0
4	2-Nov 09:30	Not frozen 3°C	Felt fabric (2 layers)	33.5	39.6	**21.4** (4d)	22.6 (4d)	-1.0	-3.0	4.0
5	5-Nov 12:12	Not frozen 1.5°C	Felt fabric with plastic	38.0	51.5	27.5 (7d)	30.1 (7d)	1.0	3.0	13.0
6	6-Nov 09:40	Not frozen 1°C	Felt fabric with plastic	32.5	40.3	**20.5** (6d)	**19.7** (6d)	-1.0	-6.2	--
7	9-Nov 09:20	Frozen -2°C	Insulated tarp	35.5	39.7	23.2 (4d)	23.7 (4d)	-3.0	-11.0	-2.0
8	14-Nov 08:25	Frozen -1.5°C	Felt fabric	34.3	38.6	**22.2** (7d)	**22.2** (7d)	-3.0	-3.0	-2.5 surface
9	15-Nov 11:15	Not frozen 2°C	Felt fabric with plastic	33.2	38.4	**22.2** (6d)	**19.4** (6d)	0.0	-6.5	10.5 surface

[1] Ambient air temperature at time of cast as indicated by Concrete Test Reports.

[2] Red colour denotes non-compliance.

[3] Minimum ambient air temperature within 24 hours after placement from temperature monitoring, where available. Where not available, from Environment Canada historical weather for Calgary International Airport.

[4] Minimum internal concrete temperature within 24 hours after placement from temperature monitoring, where available.

ANALYSIS OF TEST RESULTS

Six of the tests were conducted on concrete placed between 0°C and -5°C ambient air temperature, and the remaining three were conducted on concrete placed above 0°C ambient air temperature. No tests were conducted when concrete was placed at the ambient air temperature below -5°C or below -15°C, as required in the testing protocol.

Two tests were conducted on concrete placed on frozen ground (Tests 7 and 8). At one location (Test 7) the concrete was protected by an insulated tarp, and Test 8 was protected by felt fabric. Test 7 met the 70% strength requirement at 4 days, while Test 8 did not meet the 70% strength requirement at seven days, for both the field cured specimens and the cores.

Five of the tests were conducted with temperature monitoring on the concrete interior, two of the tests were conducted with temperature monitoring at the surface only, and the remaining two tests did not have temperature monitoring conducted.

The results of the testing indicate that the plastic properties were compliant with City of Calgary specifications, and that the compressive strengths of the laboratory cured specimens met the required minimum strengths at 28 days. In two cases (Tests 1 and 3), the minimum 28-day compressive strength of 32 MPa was not met on laboratory cured specimens tested at 7 days. Test 1 met the 70% strength requirement at three days for both the field cured specimens and the cores. Test 3 met the 70% strength requirement at six days for the field cured specimens, but not for the cores.

An analysis of all tests conducted for placing temperatures between 0°C and -5°C indicates that only one test (Test 7), met all strength requirements. It should be noted that the concrete for this pour was placed on frozen ground, which was not removed, had an internal temperature within the first 24 hours after placement of -2.0°C, and was the only pour identified as being protected with an insulated tarp. The protection continued for four days from the time of placement. All other tests conducted for placing temperatures between 0°C and -5°C failed either the field cure compressive strength test, the core compressive strength test, or both.

The protection of the concrete surfaces with the felt fabric and without plastic cover not only does not prevent moisture loss due to evaporation but also results in a desiccated concrete surface as the moisture is wicked by the fest fabric. Therefore this type of surface protection may be detrimental to the concrete surface and the risk of compromised weak paste on sidewalk surfaces is high.

FIELD OBSERVATIONS

In the fall of 2014 some of the test sites were observed for signs of damage. Some of the damage noted on the concrete sidewalk surfaces and panel cracking could not have been explained by construction traffic at the locations where the deficiencies were noted (Photo 1, 2 and 3). Some of the curbs and gutters appeared to have more cracks and more damage related to snow clearing operations (Photo 4) but, since the number of test data points was small, these findings cannot be statistically validated at this time.

Photo 1

Photo 2

Photo 3

Photo 4

CONCLUSIONS AND RECOMMENDATIONS

The testing program summarized in this report and the field observations raised the following issues.

1. Even at low temperature ranges available for the review, 62% of concrete cores failed to meet the strength criteria. It should be noted that the ambient temperature of Test 1 was above the CSA temperature ranges for cold weather concreting and was excluded from the study.

2. It is not expected that testing at lower temperatures would produce compliant results when the top range temperatures were failing the protocol.

3. Plastic tarps do not provide adequate protection against freezing.

4. Placing filter fabric directly on the fresh concrete surface wicks the surface moisture away from concrete as wetting of fabric is not possible in winter. A dry concrete surface in cold conditions cannot hydrate properly and is prone to desiccation, dusting and scaling.

5. There was no evidence to support claims that frozen soils are always replaced prior to concrete placement. Concrete placed on November 9 and November 14, 2013 was placed on frozen subgrade and the risk of frost heave is high in those locations.

6. There is not enough data to develop any correlation between the temperature and the concrete core strength. The relationship is more complex and depends on the temperature history before and after concrete placement, type of protection, subgrade conditions, and the type of concrete. Similarly, a comparison with the field cured cylinders does not reflect the true condition of the concrete in the sidewalk as the dimensions of the 100 mm by 200 mm cylinders and the thickness of the sidewalk placed on ground would result in a different thermal behaviour.

7. The test results, albeit only within the upper temperature ranges recommended for this study, did not support claims that the CSA and ACI cold weather concrete protection does not need to be followed to make durable concrete. It should also be noted that the CSA and ACI guidelines were developed after many years of experience and a large amount of data and the study conducted by The City will likely remain statistically insignificant.

8. Alberta Ready Mixed Concrete Association (ARMCA) did not endorse any relaxation of the CSA specified curing regime for off-season concrete flatwork construction.

9. Future research should include more data, including lower temperature ranges that were not captured in this study, to provide a statistically valid analysis of the impact of the current off-season construction methodology on the durability and strength of concrete flatwork.

REFERENCES

ACI 306R-10, *Guide to Cold Weather Concreting*, Manual of Concrete Practice, 2014 American Concrete Institute, Farmington Hills, Michigan.

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