

Challenges with Construction of Portland Cement Concrete Pavement at Calgary International Airport

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Abstract

In preparation for construction of a parallel runway at the Calgary International Airport in the spring of 2011, concrete pavement had to be constructed to realign Gates A1–A10. Concrete mixes were developed for central batch production for both paver and hand placement methods. In addition, winter conditions required concrete delivery from a local concrete ready-mix supplier. The construction schedule required the paved sections to be open to aircraft traffic three weeks after pavement construction. A maturity method was developed to estimate early age compressive/flexural strength of the concrete pavement. This paper presents the process utilized in developing the concrete mix design to meet the project requirements for Cement Stabilized Base (CSB) and the Portland cement concrete mix, the development of the plant mix, and the construction methodology. Additional challenges with pavement construction in winter conditions are highlighted, including CSB and concrete placement, curing conditions, control joint construction, and instrumentation for maturity of concrete determination. The verification process for final acceptance of the product is described, including durability testing and pavement design review. This project demonstrated that concrete pavement can be constructed under accelerated schedule and during adverse weather conditions with the quality of the pavement not compromised and the construction schedule successfully managed.

Introduction

The pace of construction has been increasing steadily and there is a growing demand for year-round construction, even in adverse climatic conditions. Typically, earthworks and placement of granular materials are limited to above freezing temperatures to achieve a specified level of compaction; however, concrete construction may continue at lower ambient temperatures. The methodology for placing and curing of concrete during cold weather is covered in the ACI Manual of Concrete Practice in Section 306R – Cold Weather Concreting and Section 306.1 – Standard Specification for Cold Weather Concreting. One of the objectives of cold weather concreting is to provide protection of the concrete at early age to prevent damage from freezing and thawing. That protection is frequently extended to provide adequate curing for strength and durability of concrete. Concrete curing is important to provide the moisture required for cement hydration and reduction of porosity for optimum properties to be developed. The importance of curing cannot be understated as concrete structures rarely fail due to insufficient strength. However, loss of long-term durability and subsequent reduction of service life is more widespread (Mindess et al. 2003).

Cold weather is defined as a period when, for more than three consecutive days, the average daily temperature is less than 5°C and the air temperature is not greater than 10°C for more than one-half of any 24 hour period. Protection of smaller structures and buildings is practical; however, in wide open spaces such as roads or

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airport pavements, it is more challenging to provide necessary protection for concrete for extended periods of time.

Procedures for cold weather concreting include methods for keeping newly placed concrete at above freezing temperatures; however, at extreme temperatures, concrete may freeze before it sets and before adequate protection can be provided. No additional curing can be applied under these conditions, such as moist cure, application of curing membranes, or internal curing technology developed by Delante and Cleary (2008).

Significance to Practitioners

This paper presents a comprehensive overview of the logistics of Portland cement concrete pavement construction under winter conditions. Concrete mix development, extensive procedure for concrete placement, timing and duration of protection, and monitoring during and post construction enabled on-schedule paving operations.

Background Information

Calgary International Airport (YYC) welcomes over 12.2 million passengers annually. YYC has exceeded passenger growth forecasts and the airport often experiences demand in excess of facility capacity, with limited ability to accommodate additional flights. The Airport Development Project includes a parallel runway and a new international concourse to accommodate increased passenger demand. Preliminary construction works included realignment of gates A1 to A10, which had to be completed by the spring 2011 to allow for parallel runway construction. Construction for the gate realignment commenced in April 2010 with the schedule calling for completing of concrete paving operations by October 2010. A central batch plant was set up for concrete production on site in May 2010 to meet the original schedule for paving commencing in June. Construction delays and additional works delayed the start of paving operations to October 2010 and continuing through to February 2011. Since the central batch plant was not set up for winter construction, concrete was delivered from a ready-mix concrete plant in Calgary when temperatures plummeted. Initially, 57 percent of the total pavement area was designated as critical to be in service in the winter of 2010. Critical area was later expanded to 73 percent and, in November 2010, to 83 percent. A combination of delays and expanded critical area for construction resulted in an accelerated schedule under winter conditions.

Gomaco's PS-2600 Placer/Spreader and a GHP-2800 slipform paver were utilized for the first time in Alberta (Photo 1). The PS-2600 Placer/Spreader is designed to meet high volume demands in new construction of concrete pavements. It accepts concrete from end dump trucks, conveys material to the grade, and spreads the material to the desired width and depth of the application. The GHP-2800 Slipform Paver features the most up-to-date technology to provide easier set-up operation, troubleshooting, and safety. The majority of concrete pavement was placed using the Gomaco paver. Hand pours were intended for edge panels and around services locations only. However, concrete paving moved to winter time and the majority of concrete constructed after December 2010 was placed by hand and totalled over 30 percent of the entire area. The Terraquip roller screed utilized for hand pours provided an even and smooth finish spanning over the entire 6 m wide PCC slab.



Photo 1. Gomaco's placer/spreader and paver.

Mix Design for Cement Stabilized Base (CSB)

The theoretical mix design was based on the requirement for a compressive strength of 5 MPa at 7 days and a maximum 7 MPa at 28 days. The mix was based on the maximum moisture content not exceeding 6 percent. Testing of cores obtained from the in-place CSB indicated compressive strength between 5 MPa and 7 MPa at 7 days and between 8 MPa and 10 MPa at 28 days.

Concrete Pavement Mix Design Development

The Portland cement concrete pavement (PCCP) design for the apron was based on a flexural strength of 4.2 MPa at 28 days and Class C-2 exposure in accordance with CSA A23.1-09. The concrete mix design was developed to meet the durability and flexural strength requirement. Trial batch testing was conducted to confirm the mix properties and to develop the correlation between the flexural and compressive strength of concrete. Two separate concrete mixes were designed; one for the machine pour (slip form and fixed form paving) and one for hand placement. The cement content complied with the specification minimum requirement of 310 kg/m³. Type GU Portland cement produced by Lafarge North America at their Exshaw, Alberta, Plant was utilized in the mix. Sundance fly ash was added to the mix to enhance long-term concrete durability and strength development. Fly ash concrete mixes may provide comparable durability characteristics to the high performance concrete (HPC) that typically utilizes silica fume (Day and Czarnecki 2011). In addition, the level of fly ash utilized in the mix mitigated against alkali silica reactivity potential with moderately reactive aggregate source from Calgary, and against sulphate attack on concrete in contact with soils with elevated sulphate concentrations. The mix designs and the trial batch testing results are presented in Table 1 and Table 2, respectively. The water/cementing materials ratio (w/cm) was somewhat higher for the hand pour mix with a small adjustment to the fine aggregate to produce one cubic metre of concrete.

Table 1. Concrete Mix Designs

Component	Machine Placement Mix	Hand Placement Mix
Cement (kg/m ³)	310	310
Fly ash (% by mass of total cementing mat)	20	20
Water/cementing materials	0.36	0.37
20 mm coarse aggregate (% by mix mass/m ³)	48	48
Fine aggregate (% by mix mass/m ³)	29	28
Air entraining admixture	Sika Multi-air 25	Sika Multi-air 25
Water reducing admixture	Sika Plastocrete® 161	Sika Plastocrete® 161

Table 2. Trial Batch Test Results

Mix Property	Machine Placement Mix	Hand Placement Mix
Air content (%)	5.0	6.0
Slump (mm)	10	100
Compressive strength at 7 days (MPa)	32.1	23.2
Compressive strength at 28 days (MPa)	40.4	34.7
Flexural strength at 7 days (MPa)	4.3	4.2
Flexural strength at 28 days (MPa)	5.5	5.2

The results of the concrete testing indicated that, while the results of flexural strength testing were similar for hand and machine placed concrete, the compressive strength development was slower for the hand placement mix. The mix performance characteristics was based on the flexural strength of concrete; however, since the compressive strength testing frequency was higher during paving operations, a correlation between the flexural and compressive strength was developed. The correlation was developed with laboratory samples and from the results of the quality control testing completed during the first two month of paving. The average correlation factors are presented in Table 3.

Table 3. Correlation between Compressive and Flexural Strength of Concrete

Average Flexural Strength Expressed as % of Compressive Strength			
Concrete Placed by Paver		Concrete Placed by Hand	
7 days	28 days	7 days	28 days
13.8	13.3	14.9	14.0

The correlations are consistent with the mix designs, i.e., a higher w/cm ratio typically results in lower compressive strength; however, the flexural strength expressed as a percentage of compressive strength is higher for the concrete mix placed by hand.

Cold Weather Paving Procedure

As the concrete paving was delayed to October 2010, it became evident that in order to pave the entire area designated as critical for the airport operations, concrete paving would continue in winter at temperatures below freezing for long periods of time. With limited protection from the elements available during paving, a procedure was developed to reduce the risk of damaging the concrete pavement when placed below the range defined by ACI for cold weather conditions. The procedure included subgrade preparation and protection, protection of CSB from freezing during and after compaction, maintaining CSB temperature at above 5°C prior to application of tack coat and subsequent concrete paving and keeping the temperature of concrete above 5°C for at least seven days or until 75% of designed strength was achieved. Ambient temperature ranges were defined for insulated tarps application and/or glycol lines installations. Temperature monitoring devices were installed recording hourly changes in concrete and ambient temperatures. The roles and responsibilities for all tasks were clearly defined between the general contractor, paving contractor, and testing agencies. Heating was maintained until 75% of specified strength was achieved by temperature/maturity calculation. A challenge to this protocol was how to prevent concrete from freezing prior to setting and before the insulated tarps were placed. In addition, concrete paving required timely sawcutting of control joints to prevent shrinkage cracking, which required removal of tarps from concrete surfaces. Saw cutting operations at early age relied on the initial strength gain due to heat of hydration and visual observations for potential cut ravelling. At low temperatures, the probability of thermal shock and possible cracking was high and was identified by the paving contractor.

The management plan for winter construction was altered from the original summer paving to determine temperature ranges for paving stages. Weather conditions were monitored within 12 hour intervals to confirm that the forecast conditions are not outside the temperature limits defined as winter construction for the project. The paving operations were to be ceased if lower temperatures than that defined in the winter management plan were forecasted. There was no emergency plan as below these temperatures the durability of the pavement would have been compromised and the risk was considered unacceptable.

Maturity Testing for Strength Estimation

The combined effects of time and temperature are accounted for by using a maturity function to convert the temperature history to a maturity index. The maturity index is indicative of strength development. Proper application of the maturity method provides an estimate of in-place strength development during construction. There are several inherent approximations of the method and there is no single maturity function that is applicable to all concrete mixes (Carino and Lew 2001) but the method is popular in construction for determining early strength of concrete.

The equations for the correlation between the in-situ temperatures of concrete and the strength development were derived from laboratory testing of concrete in accordance with the American Society for Testing and Materials (ASTM) C1074 – Standard Practice for Estimating Concrete Strength by Maturity Method. Testing included a machine pour mix and a hand pour mix produced at the central batch plant. Based on the laboratory results the following Strength – Maturity Relationships were developed:

$$\text{Hand Pour Concrete Strength (MPa)} = 7.575\ln M + 11.08 \quad (1)$$

$$\text{Machine Pour Concrete Strength (MPa)} = 9.935\ln M + 17.87 \quad (2)$$

Where, M = Maturity Index.

Concrete Paving Operations

Changes to CSB installation schedules resulted in an altered paving plan. An initial plan to commence concrete paving after the entire CSB was placed, in long lines running south to north, was altered to CSB placement followed shortly by tack coat application and concrete pavement in shorter lines running from east to west. This change resulted in more panels placed by hand than scheduled and a more labour intense process.

Weather was monitored closely during paving operations. CSB was not placed unless the ambient temperature was above -5°C and rising and care was taken to ensure that the subgrade soils were not frozen prior to CSB placement and compaction. The minimum temperature of CSB prior to concrete paving was $+5^{\circ}\text{C}$ and was achieved either by insulated tarps alone or by use of glycol heating lines, depending on the ambient temperature. Once the PCCP was placed and finished, the temperature probes were installed. The probes were inserted about 5 cm below the pavement surface and at the mid-section and bottom of the slab, and the temperatures were recorded continuously for seven days by data loggers. The purpose of the near-surface locations of the temperature probes was to identify the risk of low ambient temperatures on the future performance of the pavement surface. Shortly after initial set of the concrete, a non-woven filter cloth was applied top, sides, and ends of the paved lines followed by a second filter cloth layer. On the pour dates, when the ambient temperature was dropping below -5°C , insulated tarps were placed to maintain concrete temperature. The risk of damaging the surface of fresh concrete by these activities was considered to outweigh the risk of freezing the surface and compromising pavement durability. Within less than 24 hours, green cutting of control joints was setup. The filter cloth and the tarps were gradually removed at specific joint locations and the surface of the concrete was quickly covered with tarps soon after the joint was completed to minimize thermal shock and cracking. Surface temperature probes were monitored and when the temperature of PCCP was falling below $+5^{\circ}\text{C}$, glycol heating lines were placed and covered with tarps to maintain the concrete temperature at $+5^{\circ}\text{C}$ for at least seven days or until 75% of specified strength was achieved by maturity calculations (Photo 2).



Photo 2. Installation of glycol heating lines on the PCCP.

An example below (Figure 1) illustrates the temperature history of PCCP placed on November 10, 2010. Calculated maturity index indicated that the time to achieve 75% of flexural strength was 91 hours for the paver placed concrete.

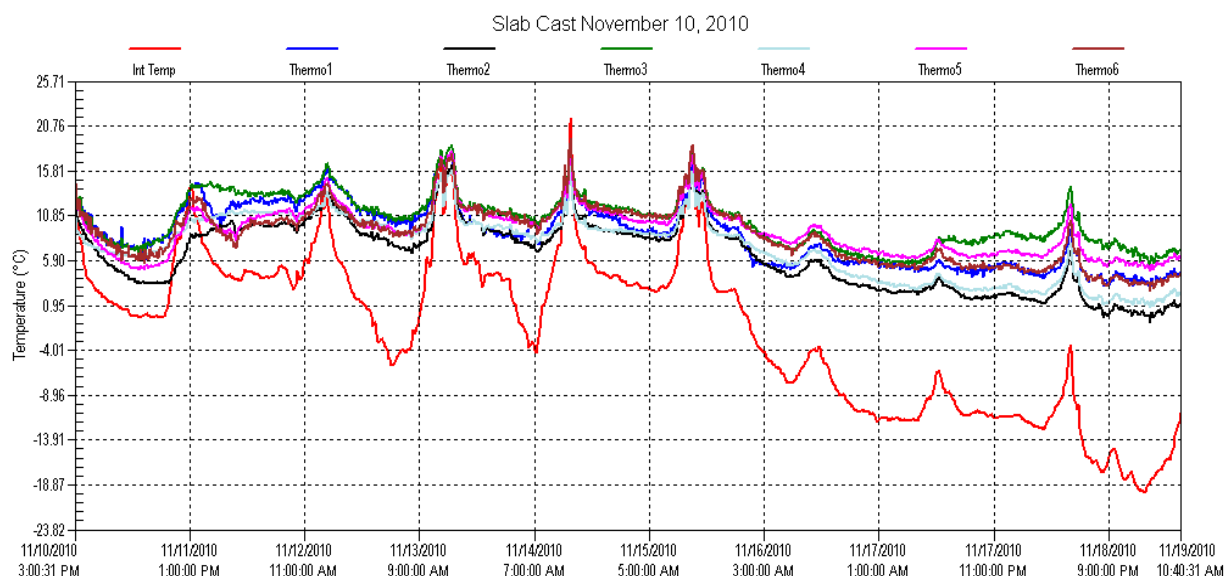


Figure 1. Temperature history of PCCP placed by a paver.

The analysis of the pours indicated that the time to reach 75% of the specified concrete strength was longer for the hand poured concrete than that of paver placed PCCP. PCCP placed by hand on November 11 and November 12 reached 75% of the specified strength after 287 hours and 295 hours, respectively (Figure 2), at a similar temperature history as the machine pour on November 10, 2011.

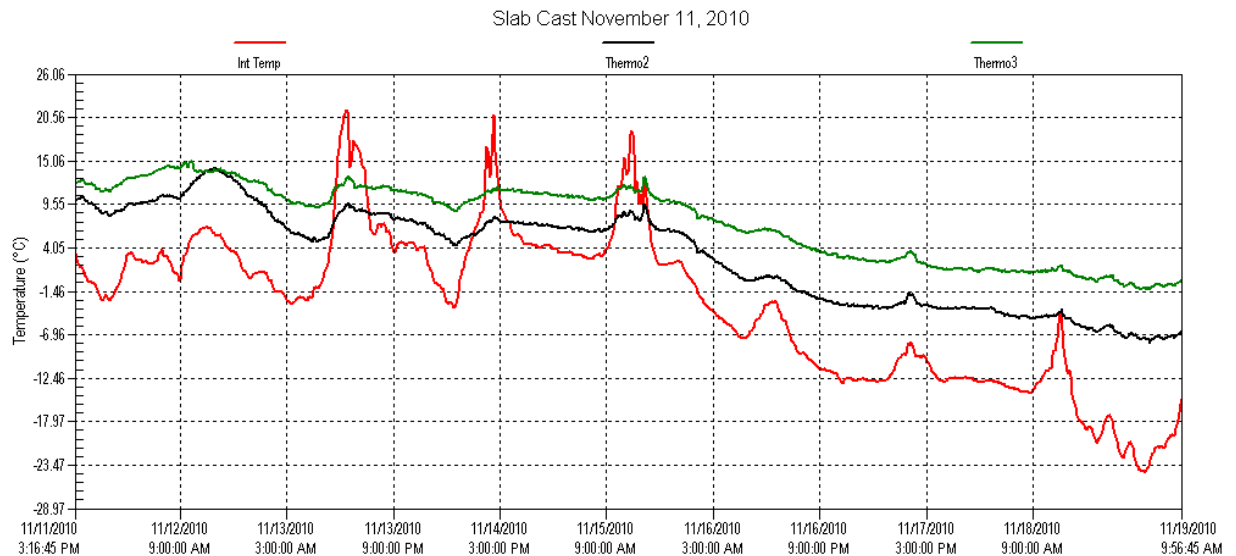


Figure 2. Temperature history of PCCP placed by hand.

Quality Control and Quality Assurance

Two independent materials testing agencies were testing soils, CSB and concrete; one for the paving contractor to satisfy quality control (QC) requirements and a second agency was testing on behalf of the owner for quality assurance (QA). In accordance with the project specifications, in case of discrepancy between the QC and QA testing results, the decision making process was governed by the QA results. The frequency of plastic properties testing and compressive and flexural strength determination was specified for the project. At the commencement of the paving operations, air and slump measurement of the concrete was completed on every truck load to help with plant production.

The overall quality of concrete was good and the average flexural strength was 5.2 MPa and the average compressive strength was 39.4 MPa. However, some deficiencies were identified; concrete strength below designed, plastic concrete entrained air below specified, and pavement thickness below designed. These deficiencies were addressed in the verification process.

Verification Process

Product acceptance in the concrete paving specification stated that concrete strength test results and the quality of pavement (durability) should be used as a basis for acceptance or rejection of the concrete. The product was defined as concrete after placement, finishing and curing. Therefore, the protocol for concrete acceptance were compressive strength of test cylinders was below specified strength was to core the locations where the low compressive strength was determined, test for compressive strength and use the ratio reported to determine the flexural strength of the area where the sample of concrete was obtained from. Core test results confirmed the compressive strength was between 32.8 MPa and 51.8 MPa at the all locations investigated. The lowest compressive strength of the core was above the specified strength for Class C-2 of 32 MPa and above 31.6 MPa derived from flexural/compressive strength ratio. Durability verification areas, where low plastic concrete air content was recorded, was to be performed on concrete cores in accordance with ASTM C457 – Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete. The acceptance criterion was that the spacing factor was not exceeding 230 μm . Linear

traverse test results on hardened concrete confirmed that no single test had a spacing factor above the maximum of 230 μm specified for freeze/thaw durability.

PCCP Thickness Deficiency

The post construction survey of the PCCP thickness identified some areas where the thickness of the pavement was below the specified. An additional pavement design analysis was conducted to define the structural risks and the pavement service life implications. The ASG-19 (AK-68-12) by Public Works Canada for airport pavement facilities and the Portland Cement Association (PCA) Design of Concrete Airport Pavement methodology was used. The PCA design method included the modulus of rupture as a function of concrete pavement thickness. The majority of the flexural strengths reported were higher than specified and as high as 5.8 MPa. A more conservative flexural strength of 4.8 MPa was used as a design input. The design based on flexural strength of the concrete pavement indicated that an increase from 4.2 MPa to 4.8 MPa allowed for a 12% reduction in the concrete pavement thickness while the maximum reduction of the actual thickness in one location was 5% of the design. Both design methodologies confirmed that the reduced thickness is not significant with respect to the structural performance and service life.

Surface Deficiencies Related to Cold Weather PCCP Placement

Some minor defects were identified during post construction inspection. The majority of the defects were caused by the tarp placement, frequently right at the concrete setting time. Cutting of control joints posed a timing issue, and at cold temperatures, some ravelling at the joints was identified. Those defects were considered minor. A number of cracks were identified in the concrete pavement that propagated, in some of the paved lines, through several panels. A review of the concrete testing in these areas verified that the concrete was compliant with the project specifications. Therefore, the investigation into the cause of the cracking was focused on the construction history and the weather conditions at the time of PCCP placement. The ability to properly cure concrete and avoid thermal shock was limited in winter with the temperatures falling to below -20°C on occasions and the risk of concrete cracking was high. CSA A23.1, Annex D, provides guidelines for curing and protection of concrete, and based on the Environment Canada data, the rate of evaporation was calculated for the day of the concrete placement. Based on the ambient temperature, concrete temperature, relative humidity, and wind velocity, the evaporation rate was $2.8 \text{ kg/m}^2/\text{h}$. Special measures should be taken to prevent excessive moisture loss from the surface of unhardened concrete when the evaporation rate exceeds $1.0 \text{ kg/m}^2/\text{h}$. A detailed procedure developed for winter construction could not have provided effective prevention against high evaporation rates. Protection from high velocity winds is not feasible at airports as the risk of FODs is not acceptable. Vapour barrier could not be utilized due to below freezing temperatures and fog spray would increase the risk of frost damage to concrete. In addition, the risk of thermal shock by exposing portions of concrete for control joint installation was high.

Discussion

This project demonstrated that under an accelerated schedule in adverse weather conditions, proper construction procedures can ensure the quality of PCCP is not compromised and construction schedules can be successfully managed. The quality of concrete, as placed, met the project requirements. The number of surface

deficiencies was no higher than in airfield construction carried out in summer construction season. The risk of concrete cracking was very high but the actual number of cracked panels was comparable with other projects carried out in the summer construction season. The detailed paving plan and well defined responsibilities were behind the success of the operations. The cost of winter construction is high with concrete plant winterizing, protection of plastic concrete, and curing and maintaining temperatures for strength development. These additional tasks are costly but were considered to outweigh the cost of delaying the project till next spring, causing a domino effect on the other projects. The process was also labour intensive; cold weather, operating equipment in cold temperature, finishing and protecting concrete, and frequent operations on a 24/7 schedule contributing to an increased labour demand. Ultimately, the owner recognized and accepted risks and additional costs with a good quality product delivered at the end.

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