Numerous laboratory test data have indicated that concretes incorporating more than about 20% fly ash or slag often perform unsatisfactorily when exposed to freezing and thawing cycles in the presence of de-icing salts. On the other hand, there are several reported cases of concrete structures incorporating significant amounts of these SCMs that have performed well when exposed to de-icing salts in the field. So far there is no clear explanation for this discrepancy. Concretes incorporating fly ash and slag may require a new laboratory test or slight changes to conventional concrete placing, finishing and curing practices to insure proper durability when exposed to de-icing salts; however, such changes are not well established. The objectives of this project are as follows:

- Compare the field and laboratory de-icing salt scaling resistance of concretes incorporating different proportions of fly ash, slag and ternary blends (with silica fume).
- Determine the effect of various key parameters such as concrete mixture design, finishing operations, and curing on the de-icing salt scaling resistance of such concretes in both laboratory and field exposures;
- Explain the somewhat lower de-icing salt scaling resistance of concrete incorporating SCMs;
- Suggest procedures, modified concrete mixture proportioning or other field practices that will improve the de-icing salt scaling resistance of concrete incorporating fly ash, slag or ternary blends.
- Provide tools to better interpret the results of the current tests, and suggest new or modified laboratory testing procedures that will better simulate the field performance of concrete incorporating SCMs exposed to de-icing salts.

The present phase of the project consisted of placing sidewalks sections using selected concrete mixtures and different finishing and curing practices by a contractor specialized in this type of work. For each of the sidewalk sections representing the different variables investigated, large slabs (1.2m x1.2m) were cast from which specimens were cored and tested in the laboratory for determining their basic mechanical properties and de-icing salt scaling resistance. The casting and finishing of the large slabs were done by the same crew used for the sidewalk sections. The scaling test on the cored specimens was done according to standard procedures and to modified procedures. Also, during the
casting of the sidewalk, using concrete from the same batch, specimens were cast on site according to the standard laboratory test procedures. These "laboratory-type" specimens were subjected to the same tests as the "cored" specimens, and their resistance to de-icing salt scaling were compared and will be compared to that of the sidewalk sections subjected to natural exposure conditions in the field.

In order to evaluate the effect of the time of casting (and maturity of the concrete) on scaling resistance, selected sidewalk sections were cast in the Spring and in the Fall of 2002.

Based on the results of this study, the following conclusions can be drawn:

**General Conclusions**

The results have shown once again that according to the ASTM laboratory test, the use of SCMs generally decreases significantly the de-icing salt scaling resistance of concrete. Whereas, the visual evaluation of the sidewalks after one winter (~10 freeze-thaw cycles) showed that the concrete incorporating SCMs perform relatively well. This confirmed published data suggesting the actual ASTM laboratory test (C 672) not being adequate for evaluating the de-icing salt scaling resistance of concrete incorporating SCMs. However, the results also show that most of the specimens of the concrete incorporating SCMs scaled significantly less when tested according to BNQ standard in comparison to those tested according to ASTM C 672. Also, the visual evaluation of the sidewalks after one winter appeared to be more in line with the results of the specimens tested according to BNQ procedure. This procedure represents, therefore, a promising laboratory test for evaluating the de-icing salt scaling resistance of such concrete.

The lab results have shown that the use of curing compound, especially during the fall, increased significantly the scaling resistance of the concrete incorporating SCMs. However, the delay of the final finishing (presumably after the bleed water has disappeared) did not improve the scaling resistance of concrete incorporating SCMs. This is probably due to the fact that the bleeding of the concrete mixtures investigated was negligible.

**Specific Conclusions**

For sidewalks cast in the Spring 2002:

- The use of fly ash decreased the scaling resistance of the concrete tested according to ASTM, but it did not significantly affect the scaling resistance of the concrete tested according to BNQ standard.
- Due to the high air content of the 25% slag concrete mixture, this mixture performed better than the control concrete in terms of de-icing salt scaling resistance. The use of 35% slag decreased the scaling resistance of the concrete tested according to ASTM but it did not when tested according to BNQ.
- The finishing after the bleeding did not improve the scaling resistance of the concrete mixtures investigated.
• In general, the samples with field-type finishing (usual field practice made by professional finishers) scaled more than those using lab-type finishing (finished according to ASTM procedure).

• For both the lab-type (slabs) and field-type (cores) specimens tested at 28 days, the use of curing compound increased the scaling resistance of the fly ash concrete mixtures but decreased that of the slag concrete mixtures. When tested at 180 days, the use of curing compound enhanced significantly the scaling resistance of all the concrete mixtures.

• In general, the use of sand or geotextile at the bottom of the molds (to provide some drainage) used for the scaling test did not significantly improve the scaling resistance of the concrete made with SCMs when tested according to ASTM standard.

• The inter-lab study has shown that the reproducibility of the BNQ test was acceptable for the control and the slag concrete mixtures. However, for the fly ash concrete mixtures, the reproducibility was relatively poor i.e. specimens from 2 labs (out of seven labs) failed to pass the test.

• The increase in concrete maturity in the field increased the scaling resistance of the concrete significantly, except for that made with ternary fly ash-SF cement (TerC³). It seems that the low air content played a greater role than anticipated.

• The visual evaluation of the sidewalks after one winter (~10 cycles of freezing and thawing) confirmed the severity of the ASTM C 672 procedure and the adequateness of the BNQ procedure to better evaluate the performance of concrete made with SCMs to the de-icing salt scaling resistance.

For sidewalks cast in the Fall 2002:

• The use of fly ash decreased the scaling resistance of the concrete tested according to ASTM, but it did not when tested according to BNQ standard.

• The use of cement TerC³ decreased the scaling resistance of the concrete tested according to both ASTM and BNQ test procedures.

• In general, the samples with field-type finishing (usual field practice made by professional finishers) scaled marginally more than those using lab-type finishing (according to ASTM C 672).

• For a curing compound regime, the field conditioning seems to decrease the scaling resistance of concrete compared to the lab conditioning (mainly due to the low temperature in the field). Whereas, for a wet curing regime, the lab conditioning seems to decrease the scaling resistance of concrete compared to the field conditioning, especially for concrete made with SCM.

• The use of curing compound enhanced significantly the scaling resistance of the concrete mixtures incorporating SCMs.

• The use of geotextile at the bottom of the molds used for the scaling test did not improve the scaling resistance of the concrete made with SCMs when tested according to BNQ standard.

• The inter-lab study has shown that the reproducibility of the BNQ test was acceptable for the control concrete, but was not for the fly ash concrete and the concrete made with cement TerC³.

• The field evaluation shows that the control concrete and the concrete made with 25% fly ash performed well after one winter (~10 freeze-thaw cycles) whereas, the
concrete made with cement TerC$^3$ showed some scaling. This confirmed that the ASTM C 672 procedure is presently inadequate to evaluate the performance of concrete made with SCMs to the de-icing salt scaling resistance. It appears that the BNQ test is yielding more realistic results.

**Recommendations**

Based on the above, it appears that the BNQ procedure is a promising laboratory test to evaluate the de-icing salt scaling resistance of concrete incorporating SCMs. The BNQ standard differs from the ASTM C 672 in the following points:

- The BNQ standard does not require brushing after the bleeding, i.e. the slabs are simply covered with a plastic sheet immediately after finishing with a wooden trowel.
- The BNQ standard requires a moist curing period of thirteen days followed by a fourteen days period of drying and seven days period of re-saturation of the surface with a solution of 3% NaCl.
- The scaling residues are collected and weighed after 7, 21, 35 and 56 cycles of freezing and thawing, and the cycles continue during the weekends as well.

It is recommended the BNQ procedure, not the ASTM procedure, be used for the evaluation of de-icing salt scaling resistance of concrete incorporating SCMs. However, the present study has also shown that the reproducibility of the BNQ test can be relatively poor for fly ash concrete mixtures. It is further recommended that additional research be conducted to refine the BNQ test for adoption as a national standard such as a CSA Standard. The research can be divided into two parts:

- Fundamental research: to explain why the specimens tested according to BNQ procedure scale less than those tested following the ASTM protocol.
- Experimental research: to suggest modifications to the existing BNQ test procedure (number of specimens, freezer operations...) in order to improve the reproducibility of the test, especially for fly ash concrete.

**References**
