1987–1988 City of Ottawa, Ontario, Canada Deicer Field Trials

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An earlier alternative deicer assessment study conducted for the city of Ottawa by Sypher:Mueller International Inc. recommended calcium magnesium acetate (CMA) and sodium formate (NaFo) for further evaluation in a set of winter-long urban field trials. Although this program encompassed associated subject areas—such as a citywide public opinion survey, an environmental assessment of NaFo, CMA, and road salt (NaCl), and an assessment of imposing a Canadian Standards Association standard for upgraded parking garage construction into a city bylaw—this paper only summarizes the technical evaluation of the effectiveness of each deicer: CMA, NaFo, and NaCl. The environmental assessment addressed current research being conducted by other organizations on the impact of all three deicers on soil and vegetation, aquatic biota, water quality, vehicle corrosion, structures, and health and safety. The field trials involved a vehicle instrumented with an electronic decelerometer which was dispatched during storm conditions over a controlled route of city of Ottawa roads to gather quantifiable data (in percent g deceleration) vehicle braking performance on deicer effectiveness. It was found that both CMA and NaFo are effective chemical deicers; however, both lag in speed of effect relative to salt to varying degrees. The residual effect of any of the three deicers tested appeared to be negligible in an urban bare pavement policy environment. The application factors relative to that of road salt were confirmed to be 1.0 for NaFo and 1.6 for CMA.

The pursuit of alternatives to sodium chloride (NaCl) for snow and ice control has grown dramatically in recent years, and several U.S. state governments, provincial governments, the city of Ottawa, and private agencies are actively exploring alternatives.

In response to this need for an evaluation of alternatives to NaCl, the city of Ottawa contracted Sypher:Mueller International Inc. An initial deicer assessment study identified calcium magnesium acetate (CMA) and sodium formate (NaFo) as promising alternatives. Preliminary field trials with both CMA and NaFo were promising. However, to be confident that these alternative deicers are effective, safe, and environmentally sound in an urban environment, a more extensive program was initiated for the 1987–1988 winter. This program included

- A full season of field trials with a vehicle instrumented with an electronic decelerometer gathering data on the effectiveness of CMA, NaFo, and NaCl;
- A survey of public attitudes toward salt damage and willingness to pay for potential gains resulting from the use of alternatives;
- An examination of the impact of passing into bylaw the draft Canadian Standards Association specification for salt resistant structures;
- A benefit-cost analysis on the economic impact of using the alternative chemicals; and
- An environmental assessment of NaCl, CMA, and NaFo as a deicers.

However, it is the actual field trials data gathering and the associated analysis of deicer effectiveness that is the subject of this paper. The benefit-cost exercise is also summarized.

FIELD TRIALS PREPARATION

The effectiveness of CMA, NaFo, and NaCl was measured using an electronic decelerometer installed in a dedicated test vehicle and a predefined test procedure over a controlled route of city streets. This data was averaged to determine the effectiveness of each deicer. This section of the report describes each of these elements in greater detail.

Test Instrument—Electronic Decelerometer

The decelerometer was equipped with a high-speed microprocessor utilizing electronics technology to achieve low power consumption, wide operating temperature range, and accurate results. Mounted on top of the decelerometer was an eight-character liquid crystal display used for communicating the test results and various messages to the operator. The decelerometer used an elimination algorithm to determine the deceleration a vehicle experienced when the brakes were applied. The decelerometer required the vehicle deceleration to remain constant for a minimum of 0.25 sec for it to have recorded that value as a valid stop.

The elimination algorithm used by the decelerometer was activated as soon as the brake was applied. The decelerometer measured the vehicle deceleration every 2.4 msec until 16 values had been acquired. These readings were averaged and compared to the average of the previous 16 readings. If the difference was less than 6 percent of the current value, the decelerometer assumed constant deceleration had not been reached; all measurements acquired to that point were cleared and the algorithm was restarted.

When the brakes were released, the algorithm stopped. If less than 96 valid, consecutive measurements were recorded, the decelerometer did not display any value; instead it displayed ":ERROR" to indicate an invalid stop. After the max-

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imum number of deceleration values had been recorded, the decelerometer automatically printed the values, the average of the values, and the date and time the tests were performed.

Test Routes

Two skid friction test routes were defined at the onset of the winter: a low-traffic-volume circuit (Pleasant Park) and a high-traffic-volume circuit (Smyth Road). Both routes were selected for several common reasons:

1. The proximity to a winter maintenance yard with weigh scales made it possible to determine exact weights of deicer spread.
2. The historical traffic data indicated uniform traffic flow throughout each deicer test section.
3. The length of each route was long enough to accommodate a number of skid friction test patches, which makes possible (a) a large number of points per deicer per test loop for averaging purposes, (b) reviewing of test patches per loop to confirm repeatability of results, and (c) allowing the test vehicle enough room to perform test patches away from the junction of deicer sections in order to minimize the effect of "tracking."
4. The uniform direction of the route (east-west) eliminated the wind direction variable from the deicer comparison.
5. The small number of peripheral salt beats feeding onto the test route minimized chemicals from "tracking" onto other deicer test sections and skewing the test results.

Pleasant Park Route—Low Volume

The low-volume route used for the trials was Pleasant Park, a two-lane, low-speed (40 kph), low-traffic residential street with an average daily 12-h traffic level (7:00 a.m.–7:00 p.m.) of 4,047. The test vehicle performed 25 predefined skid test patches per test loop: 4 patches per deicer per direction, plus 1 final skid test on an adjacent untreated section of road. The CMA test section was 1.21 km in length, the NaFo test section was 1.98 km (including the two feeder salt routes), and the NaCl test section was 1.25 km.

Smyth Road—High Volume

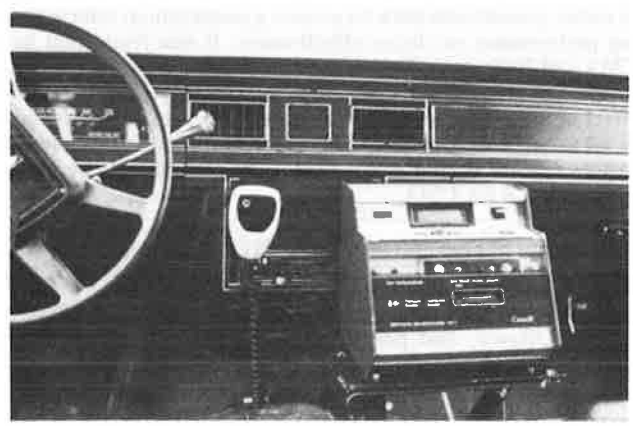
The high-volume route used for the trials was Smyth Road, a four-lane, moderate speed (60 kph), high-volume commercial road with an average daily 12-h traffic level (7:00 a.m.–7:00 p.m.) of 17,167. In order to minimize the interruption of traffic flow, the test vehicle was limited to executing 18 predefined skid test patches per test loop: 3 patches per direction per deicer. No adjacent untreated section was tested. The CMA test section was 2.2 km in length, the NaFo test section was 1.5 km, and the NaCl test section was 2.6 km.

Test Vehicles

Five vehicles were dedicated to the project: a skid test vehicle, a warning van, and three dedicated spreader trucks. The test vehicle was a 1984 Ford LTD [Figure 1(a)] instrumented with digital Tapley meter [Figure 1 (b)]. A warning van trailed the skid test vehicle during testing events to discourage regular traffic from following the test vehicle close enough to create an accident situation. A typical spreader truck used is shown in Figure 1(c).

(a)

(b)



(c)

FIGURE 1 (a) Test vehicle, (b) digital decelerometer, (c) spreader truck.

Test Procedure

The test procedure used by the test team throughout the winter is summarized as follows:

1. Storm confirmation by the city of Ottawa;
2. City contacts spreader drivers, test vehicle driver, and the warning vehicle driver;
3. Spreader drivers weigh loads and record weights before dispatching from yard;
4. Spreader drivers also agree on and record start time for spreading the deicer sections before dispatching;
5. Test vehicle and warning vehicle meet at the last skid test patch on the route of interest before initiating skid tests;
6. Spreader trucks weigh loads and record weights after stripping their respective sections; and
7. Skid test patches were continued until the road conditions stabilize, as seen by the actual skid test results (all skid test patches were performed with the test driver initiating the brakes after attaining a speed of 40 kph).

Analysis Procedure

Data was digested from three sources:

1. Deicer usage data—this data included date, spread start time, amount spread, and distance (2-lane km) of road the deicer was applied to for each deicer application. The spreader drivers supplied this data after each storm.
2. Skid friction data—this data included a time stamp of each skid friction test loop and a printout of the 25 predefined test patches (in percent g deceleration) for each storm. The test vehicle drivers supplied the electronic decelerometer printouts after each storm.
3. Weather data—this data included hourly ambient dry bulb temperature readings (°C), wind speed (knots), storm classification (i.e., light snow, freezing drizzle), and the time of day of each reading. This information was obtained from Environment Canada in the form of a Surface Weather Record.

The data from each of these three sources was entered into a database format using dBase III+. Three dBase III+ routines were written to reduce the raw information and to display this information in a legible, usable report format:

1. Deicer usage report—this routine produced a storm summary and a winter summary to date. The storm summary displayed

- Storm date,
- Storm time (24-hour clock),
- Storm number,
- Applications required,
- Application rate per deicer (kg used/2-lane km),
- Application factor (application rate of alternative/application rate of NaCl), and
- Deicer used (kg used/2-lane km).

The winter-long summary table displayed the same headings as the storm summary, with averages and totals reflecting each chemical's use throughout the winter to that date.

2. Skid friction report—this routine produced an average skid friction reading (percent g deceleration) per deicer and the number of valid stops included in that average for each test loop during the storm. Also contained on the printout were directional comparisons (eastbound skid friction averages versus westbound skid friction averages) for each deicer per test loop.
3. Weather report—this routine simply displayed the deicer application number, time, temperature (°C), wind speed (kph), and storm class at the time of each deicer application.

The information produced from each data reduction routine combined to produce a deicer braking force comparison plot used to evaluate the relative performance of each deicer. The plot tracked the performance of each deicer in percent g braking force deceleration as a function of time from the deicer application.

FIELD TRIALS ANALYSIS

The 1987–1988 City of Ottawa Deicer Field Trials were a unique set of tests where alternative chemical deicers were evaluated in a winter-long urban environment. The trials also appeared to be the first set of field tests to use a skid friction measurement device to gather quantifiable data on the performance of deicers in order to verify visual field observations. As a result, even though the original set of proposed tests only included the low- and high-traffic volume skid friction tests, the city and the project team remained flexible enough to pursue additional, alternative tests to further explore specific deicer behavior. As the field trials progressed, this appeared to be the case; several other subject areas became worthy of testing and analysis. In total, seven areas of discussion were included within this section:

- Low-traffic-volume skid friction tests,
- Directional skid friction comparisons,
- Single-lane skid friction cross-sections,
- Particle gradation tests,
- Deicer residual effects,
- High-traffic-volume skid friction tests, and
- Specific storm correlations.

Supporting the discussion and results of these seven subject areas are the data collected from 53 storm events, 100 deicer applications in all. A total of 88.3 tonnes of CMA was spread over the winter, compared with 60.8 tonnes of NaFo and 53.1 tonnes of NaCl. The NaFo initial target application rate in kg/km was 1.0 times that used for NaCl, and the application rate for CMA was 1.6 times that used for NaCl. These application factors of 1.0 for NaFo and 1.6 for CMA were determined through past field trial experience. Of the 53 storms, the skid tests vehicle and the electronic Tapley meter monitored the deicer performance in 28 storms. These 28 storms provide the foundation for the remaining discussions.

Low Traffic Volume Tests

Of the 28 storms monitored by the skid friction device, 21 compared the three deicers on the low-traffic-volume route.

These 21 sets of test results were then separated by storm temperature range into four groups:

- Greater than 0°C (greater than 32°F),
- 0°C to −5°C (32°F to 23°F),
- −5°C to −10°C (23°F to 14°F), and
- Less than −10°C (less than 14°F).

One set of test results which best represented the target deicer application rates was then selected from each temperature range. These four deicer braking force comparisons are shown in Figures 2(a) through 2(d). Figure 2 tracks the absolute performance of each deicer; in order to emphasize the relative performance between the two alternatives and salt, a second set of graphs was generated to display the percentage difference in performance between CMA and NaCl and between NaFo, and NaCl. The resultant plots are shown in Figures 3(a) through 3(d).

On both set of graphs, one point on the graph was arrived at by averaging eight skid friction test patches per deicer per loop. Therefore, one or two invalid or aborted skids per test loop had a minimal effect on the overall trends in performance produced by each chemical.

Figures 2(a) through 2(d) indicate a significant performance improvement from the untreated test section to any chemically treated test section for all temperature ranges. The salt test section, however, consistently showed a better performance than the NaFo test section. Similarly, the NaFo test section consistently showed a better performance than the CMA test section.

Directional Comparison

In order to verify that there were no unexpected anomalies in the traffic flows on the Pleasant Park loop, a directional analysis was performed on the first 10 monitored storms. Tests encompassing both a.m. and p.m. rush hour periods were analyzed to detect any directional dependencies.

Figure 4 shows both the eastbound and westbound skid test results for each deicer during Storm 9. Storm 9 began at 5:15 a.m. and continued until approximately 3:00 p.m. the next afternoon. This storm was a particularly long test, running over 10 hours. Although small differences can be seen in each graph, for the most part the eastbound skid friction averages tracked quite well with the westbound skid friction averages. The differences could be a result of

- Slightly increased traffic flow due to the morning rush hour,
- Cars temporarily parked on the side of the road forcing one direction of traffic out over the center line of the road, or
- Cars temporarily parked on the side of the road forcing the spreader truck driver out over the crown of the road.

It was assumed for the duration of the field trials that the eastbound and westbound skid friction readings tracked reasonably well and would be averaged to form a single skid friction number representative for that deicer test section. Figure 5 supports the similar conclusion with skid friction data from Storm 3, which included the evening rush hour period.

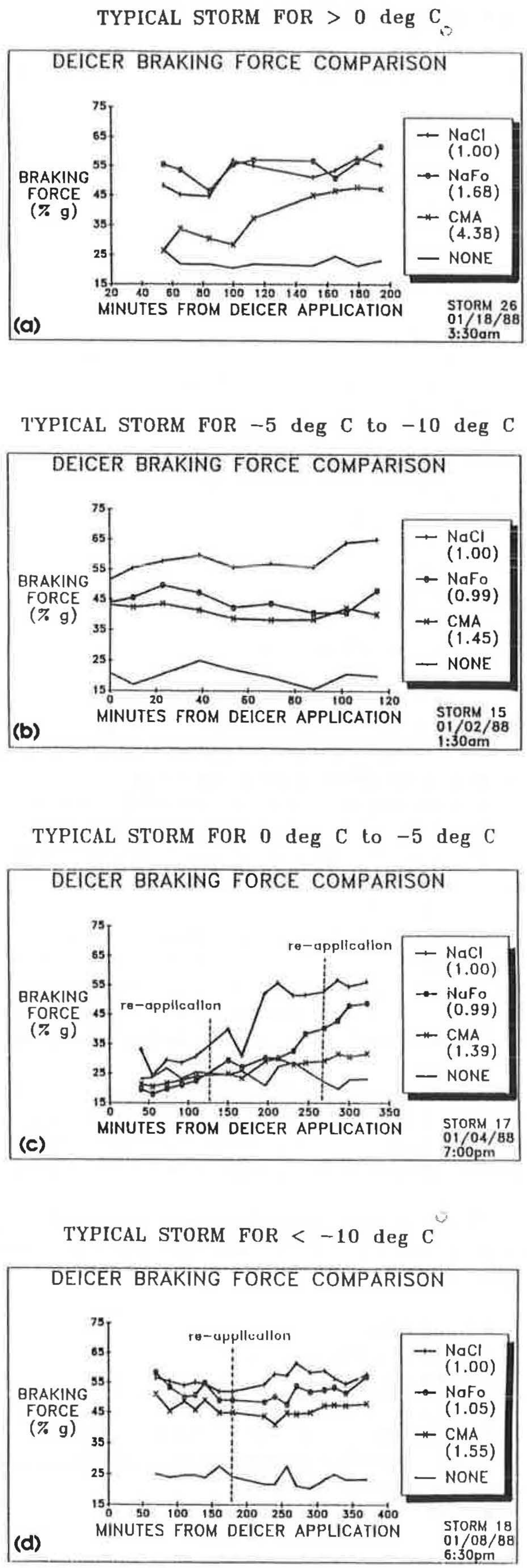


FIGURE 2 Braking performance at different temperatures.

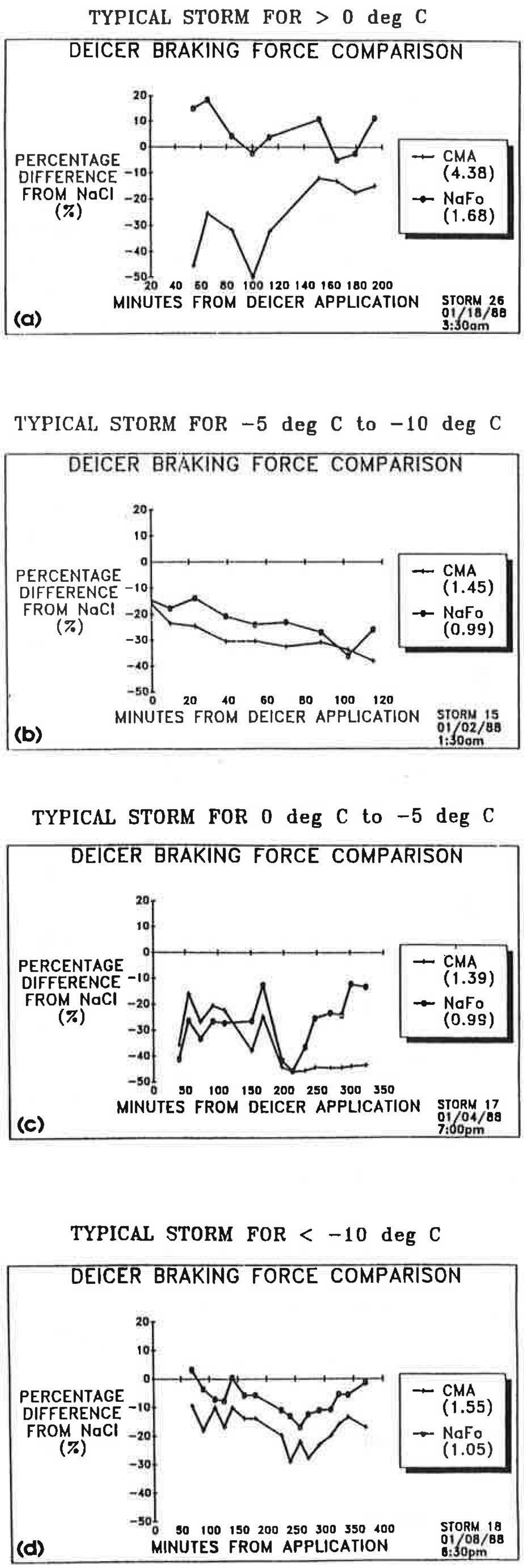


FIGURE 3 Deicing performance of CMA and NaFo compared with NaCl at different temperatures.

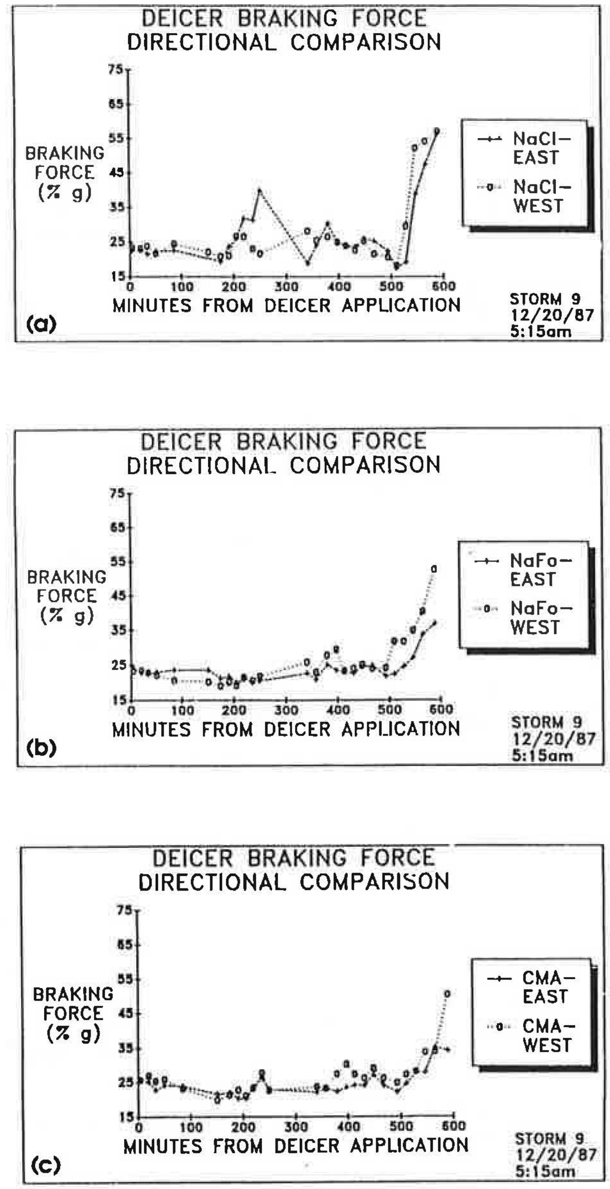


FIGURE 4 Comparison of eastbound and westbound skid test results for a.m. rush hour: (a) NaCl, (b) NaFo, (c) CMA.

Single Lane Cross-Sectional Tests

After some 26 storms the test team noticed that, even though the alternatives performed adequately in the skid friction tests to date, they did not appear to melt the snow "curb to curb" in the same manner as NaCl. Although, for the most part, cars will be running on the cleared tire paths in the center of each lane, there will be instances where a car is forced into a corrective maneuver outside the cleared tire paths. For example, a car parked on the side of the road would force the traffic out onto and over the center of the road. If sudden braking action was required at this point, the braking action would occur on a slushy section of the road. This was one reason why the city of Ottawa has adopted a "bare pavement policy."

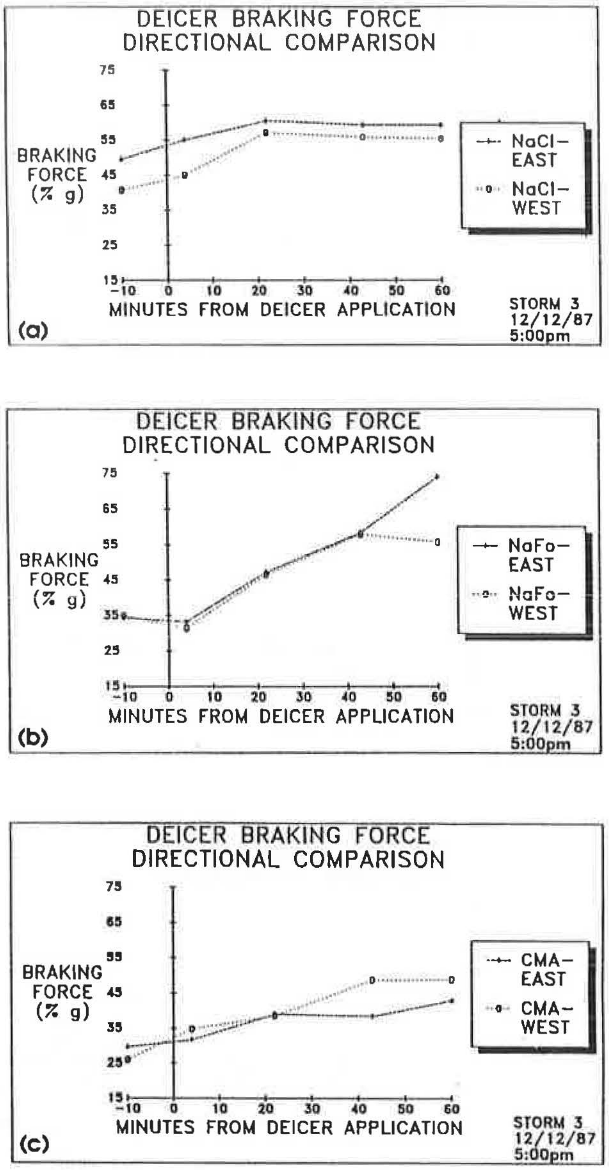


FIGURE 5 Comparison of eastbound and westbound skid test results for p.m. rush hour: (a) NaCl, (b) NaFo, (c) CMA.

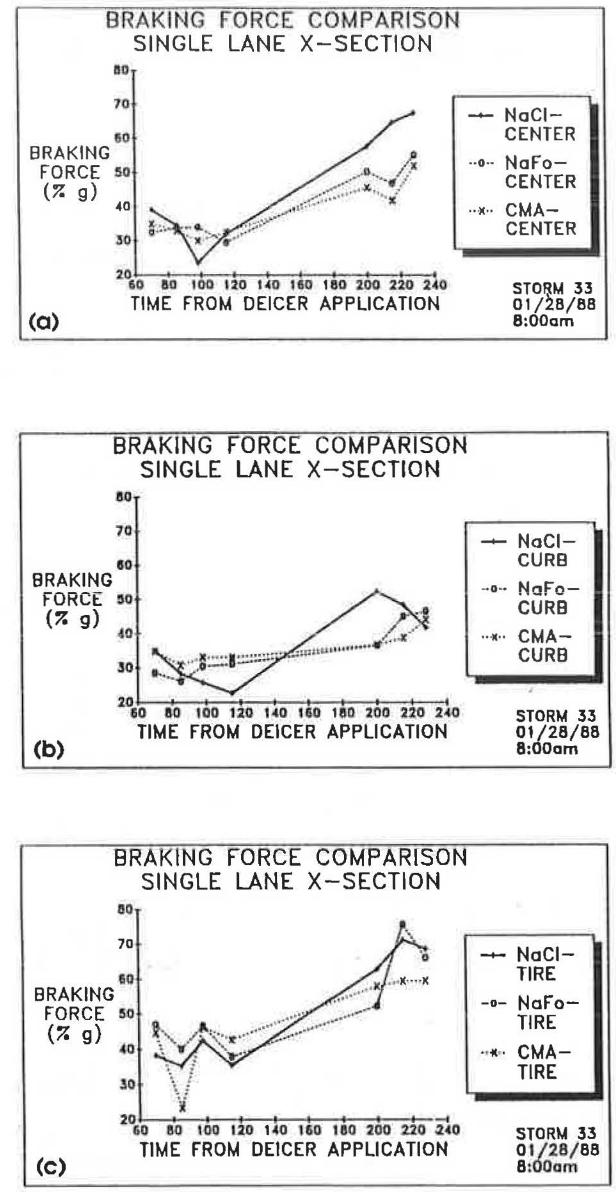


FIGURE 6 Comparison of single lane cross-sectional skid tests: (a) center, (b) curb, (c) tire.

In order to better understand this situation, cross-sectional skid friction test patches were conducted in a number of storms. The test loop was reduced to three test patches per deicer per direction. One test patch was performed as close to the shoulder as safety would allow the right tire to go. One test patch was performed where the normal traffic flow had cleared the tire paths, and the final test patch was performed as close to the centerline as safety would allow the left tire to go. Each point on these graphs now represents the result of an average of two skid friction test patches as opposed to eight on the graphs in the previous discussions.

Figures 6(a), (b), and (c) are typical results for a storm where the cross-sectional procedure was used. Figure 6(a) shows that the NaCl test section attained a higher center line skid friction reading than the NaFo and CMA test sections. Similar results occurred for the curbside test patches [Figure 6(c)]: the NaCl test section reached a higher skid friction reading than the NaFo and CMA test sections. However, in the skid test patches performed in the tire tracks, the NaFo test section achieved the highest skid friction reading. The tire paths test patches produced slightly closer results between all three deicers than did the curbside test patches or the centerline test patches.

Upon further discussion with the two alternative deicer manufacturers it was postulated that neither alternative possessed the distribution in particle size that NaCl displayed. This wide range of particle size was required for better overall melting action. This phenomenon is discussed in greater depth in the next section.

Particle Gradation

Upon closer examination of the CMA and NaFo test sections during a storm, it was discovered that the alternatives were laying dormant in the slush.

The NaFo gradation was a large uniform-sized particle (see Figure 7). With its weight and melting abilities, the NaFo particle had little trouble penetrating the snow pack to the road surface. However, once on the road surface this large particle no longer was in contact with the snow pack. The particle essentially had nothing to react with. The results of a sieve analysis performed on each deicer are shown in Figure 8. This plot illustrates the percent weight of each deicer sample that passed through various sized screen apertures.

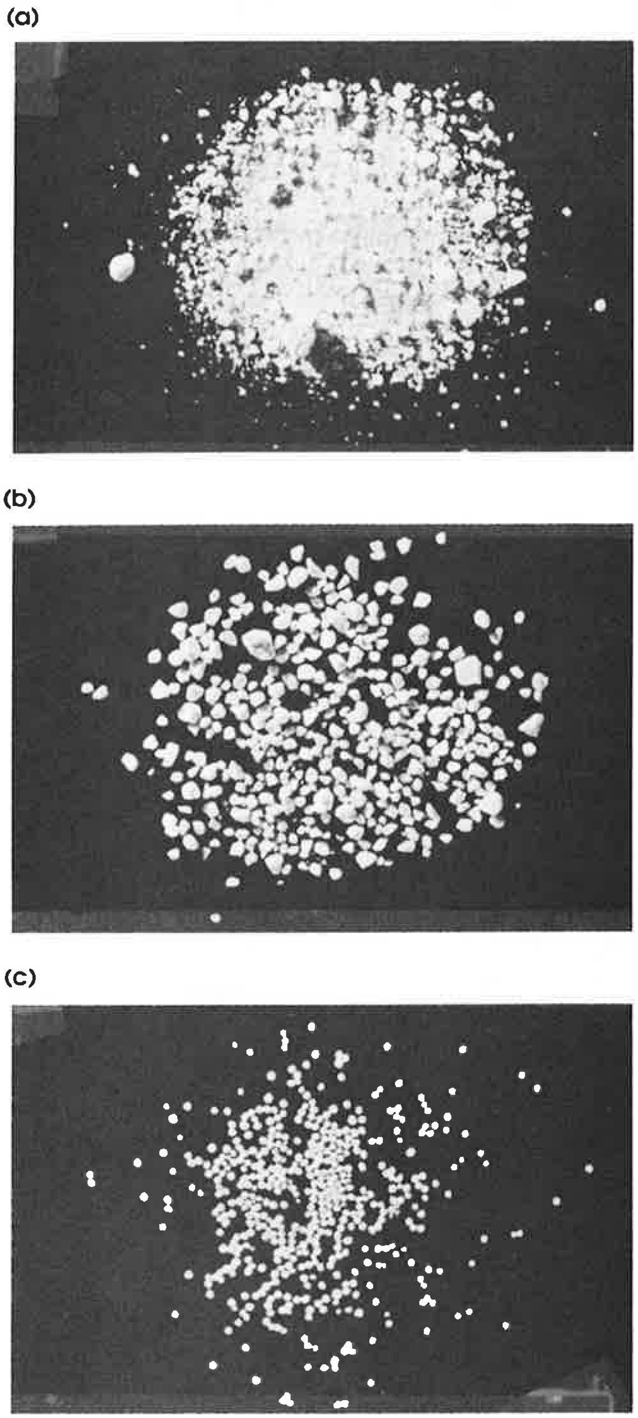


FIGURE 7 Size distribution of deicer particles: (a) NaCl, (b) NaFo, (c) CMA.

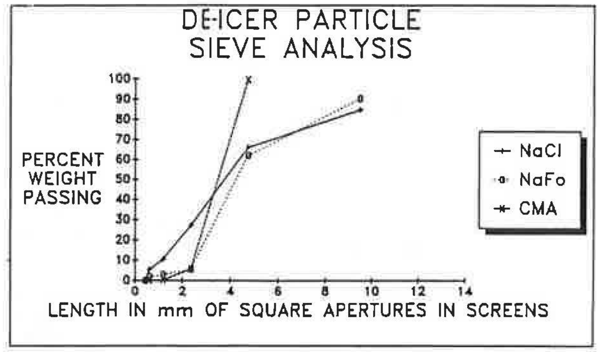


FIGURE 8 Deicer particle sieve analysis.

NaCl, on the other hand, contained a wide range of particle sizes. NaCl contained large particles to penetrate the snow pack to the road surface, which started a brine forming, as well as a range of smaller particles. This combination of particle sizes gave salt a better overall melting action.

CMA experienced the same time lag in its ability to produce curb-to-curb melting action as NaFo. The CMA gradation was also a uniform size. However, the CMA particle was much smaller. This combination of uniform and small particle size resulted in an increased period of time required to clear the road curb to curb.

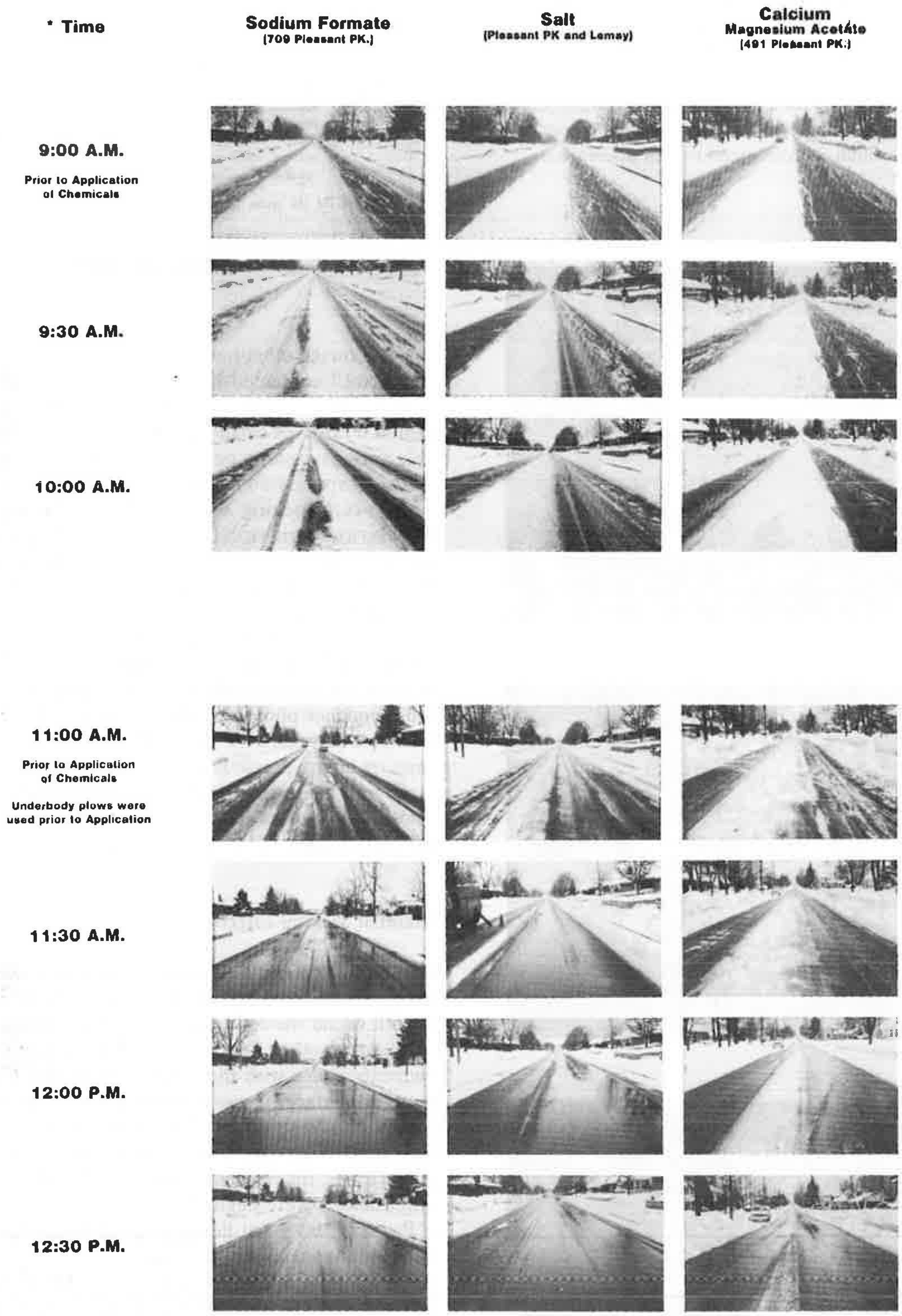
As final evidence to support the time-lag experience by the alternative deicers (relative to NaCl), photographs were shot at even time increments over the course of a storm. These time sequence photos are shown in Figure 9 (for low-volume traffic) and Figure 10 (for high-volume traffic). Again, in support of the previous discussion, Figure 9 shows that the NaCl and NaFo cleared the road, curb to curb, after 2 hr. The CMA test section still showed a center slush 3.5 hr into the photographic sequence. Figure 10 illustrates similar results.

Residual Melting Effects

Residual deicer melting effects consist of residual or unused chemicals remaining on the road surface from one storm that benefit or aid the road conditions of a following storm.

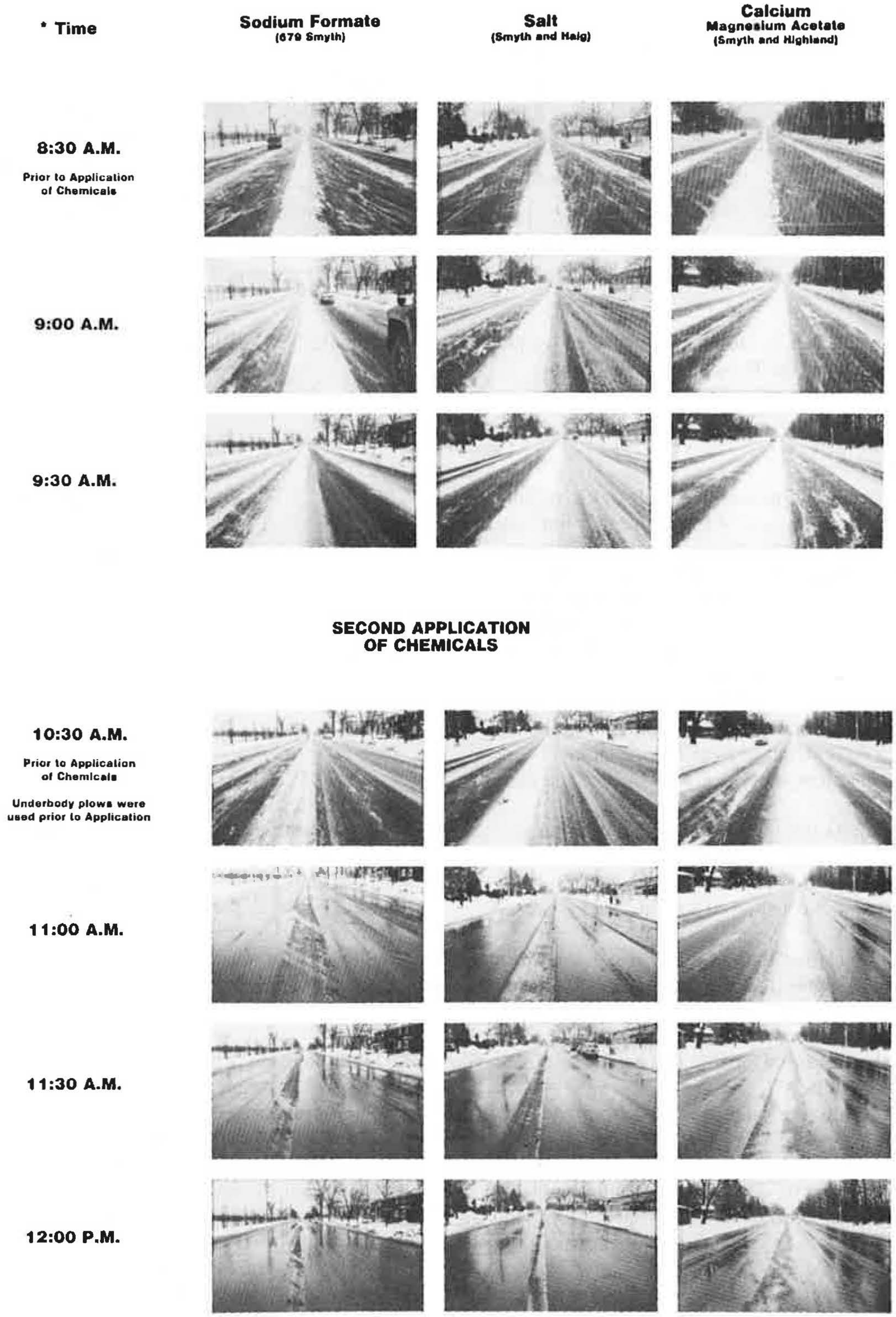
Based on other field trials conducted with CMA and our own experience with the "sticky" brine that CMA forms on the road surface, it was envisaged that CMA would possess some storm-to-storm benefits. However, based on this set of field trials in an urban environment where a bare pavement policy exists, the residual melting effects of CMA and the two other deicers were negligible.

Proof of this point lies in a storm where the skid friction test team happened to have started their testing ahead of the deicer spreader trucks (see Figure 11). This test duration was 400 minutes. The horizontal scale on the graph was truncated to better reproduce the first two hours of the test. The first test patch, 20 minutes before the first deicer application, shows very little difference between the skid friction resistance of the deicer test sections. The side road where the single untreated test patches were taken shows a slightly higher skid resistance reading. This was due to the fact that there was no measurable traffic on the untreated section and the road surface would remain as dry snow. Dry snow inherently possesses a higher



* Times given are approximate to within minutes

FIGURE 9 Time sequence photographs of deicer performance: Pleasant Park; March 2, 1988; low-volume traffic; temperature −14°C; winds SE at 9 km/hr.



* Times given are approximate to within minutes

FIGURE 10 Time sequence photographs of deicer performance: Smyth Road; March 2, 1988; high-volume traffic; temperature −14°C; winds SE at 9 km/hr.

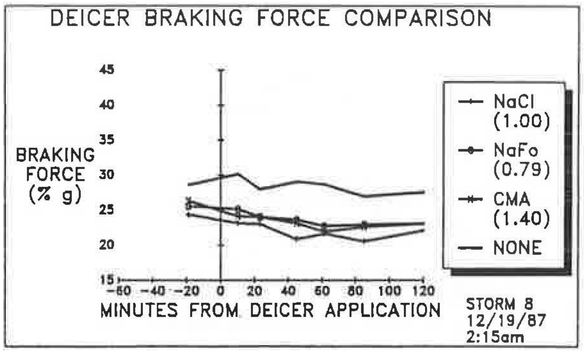


FIGURE 11 Residual skid resistance effect.

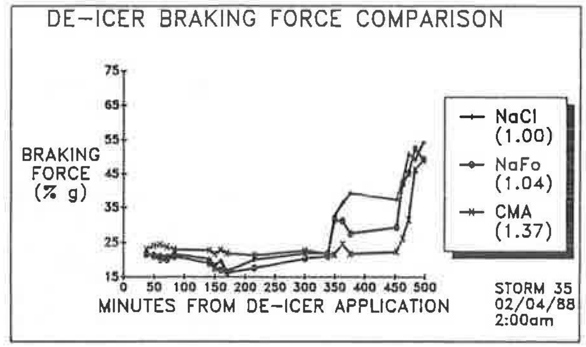


FIGURE 12 Storm 35 deicer braking performance.

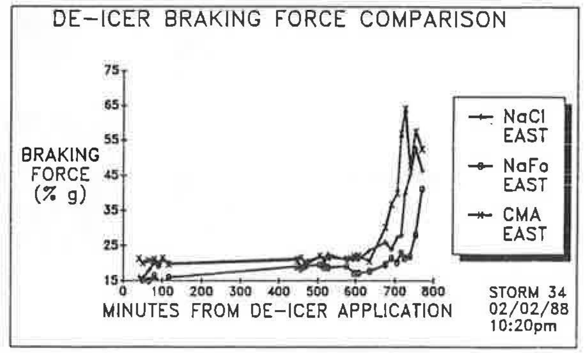


FIGURE 13 Storm 34 deicer braking performance.

skid resistance than the wet or slushy snow created by the higher volume of traffic on the Pleasant Park test loop.

High Traffic Volume Tests

Only two storms were monitored on the high-traffic-volume route, Smyth Road. Both of these storms were four and five deicer application storms that lasted upwards of ten hours. Storm 35 produced overall application rates slightly lower for the CMA test section than was targeted for the project (1.4 versus the target of 1.6). All deicer test sections tracked comparably until the morning rush hour. At that point the heavier traffic increased skid friction resistance on the NaCl test section to the highest reading (see Figure 12). NaFo obtained the second-highest skid friction, and the CMA test section experienced the lowest skid friction of all three sections. These results were quite consistent with the low-traffic-volume findings to date.

However, in Storm 34 the targeted CMA application rate was reached with quite a different result. The CMA test section attained the highest skid resistance once the evening rush started. The NaFo and NaCl showed similar skid resistance profiles (see Figure 13).

Thus, it can be concluded that, when CMA is spread in adequate volumes (1.6 times that required for NaCl) at temperatures above −10°C, CMA performs quite comparably with NaCl if there is an alternative snow removal mechanism. The snow removal mechanism in this case was the higher volume of rush hour traffic.

Although these results are quite different from the low-traffic-volume tests, they are consistent with findings from other field tests. CMA seemed to be more of a snow and ice "de-bonder" than a "melter." Thus, CMA required a mechanism for snow removal, which could either be a plow blade or high traffic volumes, to push the snow to the roadside. Also, CMA appeared to be reasonably effective when applied at the pavement-snow interface as an anti-icer. When applied on top of a snow pack, CMA required substantially more time.

Storm Correlations

Midway through January the city of Ottawa operations staff, participating directly in the deicer trials, began documenting their visual observations of the deicer test section road conditions during storms. These visual observations were initiated for three reasons:

- To compare visual observations to the actual skid friction measured between the tires and the road surface;
- To further investigate or document the earlier findings that the alternatives provided a skid resistance comparable to salt but did not clear the entire road of slush and snow; and
- To provide some documented log of storms during which, for coordination or mechanical problems, the test team was unable to monitor the storm with the electronic decelerometer.

The time at which specific observations were noted was plotted and compared with the electronic decelerometer results. The findings of this exercise were that the plotted visual observations were not always consistent with the electronic decelerometer results. Figures 14(a) through 14(d) shows examples.

Storm 26 [Figures 14(a) and 14(b)] indicates a good correlation between the visually observed road conditions and the skid friction measurements. The visual observation plot clearly shows CMA lagging in effectiveness throughout the test, as does the braking force comparison. Similarly, both graphs reflect the closeness in effectiveness between NaFo and NaCl.

However, Storm 30 [Figures 14(c) and 14(d)] does not provide consistent results. The visual observation plot shows CMA clearly lagging in effectiveness as compared with the other deicers. The braking force comparison plot shows NaFo as the deicer clearly lagging in performance for all but the final test loop.

Although visual observations complemented the use of the electronic decelerometer, it was felt that visual observations

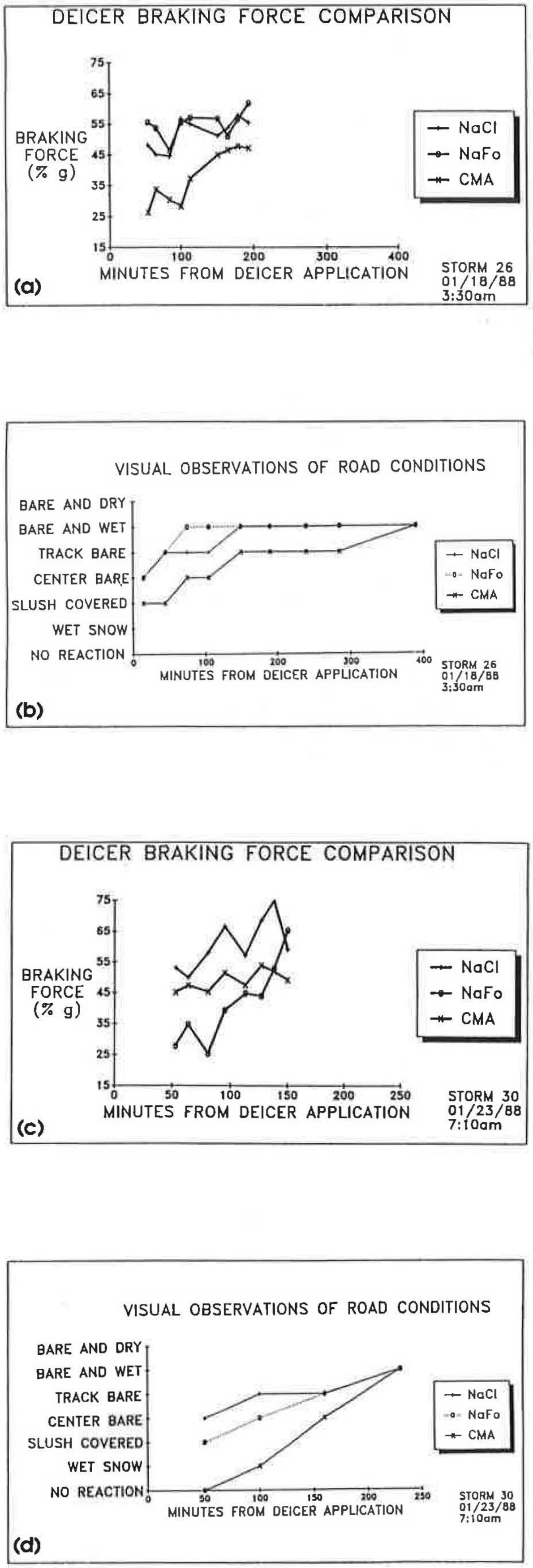


FIGURE 14 Comparisons of decelerometer results and visual observations: (a) and (b), Storm 26; (c) and (d), Storm 30.

alone did not tell a consistently accurate story. In addition, although the electronic decelerometer did provide measurable results in this set of field trials (e.g., the skid resistance between a car's tires and the road surface in hazardous conditions), it was the visual observations that helped to identify the inability of alternative deicers to produce a total melting effect while still producing comparable skid friction results.

BENEFIT–COST ANALYSIS

In comparing alternative chemical deicers to NaCl, the benefits and costs were examined from an incremental perspective; that is, what were the extra benefits and what were the extra costs.

Many of the benefits of using alternative deicers are very difficult to quantify: reduced damage to groundwater and vegetation and reduced impact on human health as a result of lowering the sodium content of drinking water. It was possible, however, to quantify reduced automobile corrosion and reduced damage to bridges and parking structures. Drawing on data from other studies, it appeared that the use of noncorrosive deicers would reduce automobile depreciation by approximately \$146/year/household based on the vehicle/household ratio in Ottawa. The effect of reduced damage to bridges and parking structures was calculated to be approximately \$154/year/household. This effect would not be recognized directly by the taxpayers but would flow through to them as a result of reduced provincial taxes, municipal taxes, parking charges, rents, and condominium fees.

The costs of using alternative deicers would be significant. In the city alone the use of CMA would add \$46 million/year to the City budget, while the use of NaFo would add \$11 million/year. These costs are based on an average annual winter salt use by the city of Ottawa of 24,000 tonnes, a salt cost of \$36/tonne, a CMA cost of \$1200/tonne, and a NaFo cost of \$480/tonne. On a household basis this translates to an additional cost of \$342/year for CMA and \$82/year for NaFo.

Unfortunately, these benefits would not be realized unless the entire region was salt free, so similar costs would be borne by neighboring municipalities. The annual incremental benefits and incremental costs of using an alternative chemical are as follows:

Description	*Amount (millions of dollars)*	*Amount (dollars per household)*
Cost		
Incremental cost of CMA	46.3	342
Incremental cost of NaFo	10.9	82
Benefits		
Reduced automobile depreciation	19.4	146
Reduced structural damage	20.5	154
Total quantified benefits	39.9	300

This tabulation results in benefit-cost ratios of 0.88 for CMA and 3.66 for NaFo. Benefits related to reduced groundwater damage, vegetation damage, and health impacts have been quantified and are included in this calculation.

CONCLUSIONS

A detailed examination in an urban environment of the two alternative deicers (CMA and NaFo) led to the following conclusions:

- Both CMA and NaFo provide roadway deicing.
- NaFo lags in speed of effect relative to NaCl by up to 0.5 hr.
- CMA lags in speed of effect relative to NaCl by approximately 1 hr or more.
- For the gradation used in these field trials, both CMA and NaFo lag in their ability to melt snow and ice curb to curb in order to meet Ottawa's bare pavement policy.
- In a bare pavement policy urban environment, the residual melting effects (as determined by measuring skid resistance) of any of the three deicers tested appear negligible.
- The CMA deicer appeared to possess more of a debonding and anti-icing ability than a melting ability, as demonstrated by its much improved performance when high traffic volumes provided the mechanical removal of the snow.
- The endurance factor of all three deicers in the urban environment was near equivalent, as shown by the fact that in the majority of the storms all three deicer test sections had to have reapplications performed at the same times.
- Visual observations alone did not provide a consistent, accurate measure of surface friction.
- Electronic decelerometer readings did provide consistent, repeatable results for surface friction, but visual observations are recommended to flag any anomalies outside the tire–road surface interface.
- Because storms possessing higher than targeted application factors did not affect the relative effectiveness between alternatives, there appeared to be no reason to alter the previously published application factors (relative to that for salt) of 1.0 for NaFo and 1.6 for CMA.

RECOMMENDATIONS

- From a benefit-cost perspective and from the perspective of effectiveness, CMA is not recommended at this time for use as a deicer to achieve urban bare pavement policies. CMA should be considered as a deicer if it can be obtained for $1040 (Can.)/tonne FOB Ottawa or less.
- From a benefit-cost perspective and from the perspective of effectiveness, NaFo is recommended as a deicer to support urban bare pavement policies. However, effective use of NaFo as a deicer in Ottawa requires (a) satisfactory results of spalling and corrosion tests (which are currently under way) and (b) satisfactory results from environmental tests (which need to be undertaken), such as:

1. Soil lysimeter leaching tests;
2. Aquatic toxicity tests (i.e., short-term, static bioassays and long-term, renewal bioassays); and
3. Vegetation impact tests using NaFo in solution as irrigation water.

- Sucessful negotiations with local municipalities are required to move collectively to alternative deicers.
- Public awareness and public forum meetings are needed to confirm willingness to pay.

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