Full-Depth Reclamation with Calcium Chloride

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Low-volume secondary roads requiring rehabilitation can be restored using the full-depth reclamation process with calcium chloride to achieve increased bearing capacity, minimize frost heave damage, and reduce highway maintenance expense. Full-depth reclamation uses a pulverizer to grind the asphalt surface, blending it with the gravel base to a depth of 8 in. The road is then reshaped and approximately three-quarters of the required calcium chloride is added. Additional pulverization is performed to ensure a uniform mixture of road material and calcium chloride. Following this, the road is graded, rolled, and final application of calcium chloride is made. Testing of full-depth reclamation with and without calcium chloride addition indicates that use of the reclamation process achieves a dense, stable, granular layer, improving overall pavement strength compared to original pavement condition. The addition of calcium chloride enhances this stabilization of the granular layer 10 percent beyond strength measured in the untreated reclaimed road section. A 50 to 60 percent reduction in frost heave can be expected in reclaimed sections of road using calcium chloride.

In a full-depth reclamation process, existing bituminous surfaces are pulverized and blended with a predetermined amount of granular base material in place, resulting in a more uniform and denser base. Calcium chloride aids in this densification process and provides the added benefit of reducing frost heave. Full-depth reclamation may be used to upgrade almost any secondary roadway. Full-depth reclamation with calcium chloride is of particular benefit to roads with structural deficiencies in the surface or base course. This process will not correct subgrade deficiencies. City and suburban streets, county and secondary roads, parking lots and storage areas, as well as airport runways and highway shoulders have all benefited from the process of full-depth reclamation.

A case study of full-depth reclamation with and without calcium chloride is described to demonstrate the benefits achievable with calcium chloride addition in low-volume secondary road maintenance.

ACTIVE PROPERTIES OF CALCIUM

In order to choose projects where calcium chloride can be successfully used, a description of its active properties and their relationship to soil stabilization is necessary.

Calcium chloride is a hygroscopic and deliquescent chemical. Hygroscopicity is the property of absorbing moisture from the air; deliquescence is the property of dissolving in this moisture to form a liquid solution. When calcium chloride deliquesces, the resulting solution is hygroscopic and absorbs moisture until equilibrium is reached between the vapor pressure of the solution and that of the surrounding air. Figure 1 shows the atmospheric conditions under which calcium chloride will deliquesce. A project using calcium chloride must be located in an area where relative humidity is greater than 40 percent. Table 1 indicates the water absorption capability of calcium chloride solutions at 77°F and various relative humidity levels. Calcium chloride solutions will act to add or remove water from the environment, until equilibrium is achieved.

The vapor pressure of calcium chloride solutions is significantly less than that of water at the same temperature. Because evaporation is a direct function of vapor pressure, it takes place at a much slower rate from a calcium chloride solution versus water at any given temperature and relative humidity. Surface tension of calcium chloride solutions is higher than that of pure water—a property further inhibiting evaporation versus pure water.

The effect of hygroscopicity, deliquescence, lower vapor pressure and increased surface tension provided by a calcium chloride solution is a stabilization project that maintains an optimum moisture content longer than if calcium chloride were not present—an important factor in obtaining and retaining maximum density in a well-graded mixture.

In order to achieve soil stabilization with calcium chloride, clay soils similar to those shown by the AASHTO group A-2 classification are required. The positively charged calcium ion reduces the negative charge on the clay particle. This serves to reduce the repulsion between clay particles and the thickness of their insulating water film. The reduced repulsion coupled with a surface tension greater than plain water results in a tremendous magnification of the attractive forces between clay particles. The binding ability of the fines is thereby greatly increased as is road stability.

Calcium chloride solutions freeze at extremely low temperatures. Figure 2 shows this relationship. When a solution containing less than 29.8 percent $CaCl_2$ is gradually cooled, crystals of ice will form as the saturation curve is intersected. Further cooling will serve to increase the calcium chloride content of the remaining liquid solution with complete solidification only occurring at −67°F. Thus, calcium chloride depresses the freezing point of capillary water in soil that serves to minimize frost heave damage in road maintenance projects using calcium chloride.

PROCESS DESCRIPTION

Preliminary testing and inspection of the road must be performed before reconstruction, including the evaluation of ex-

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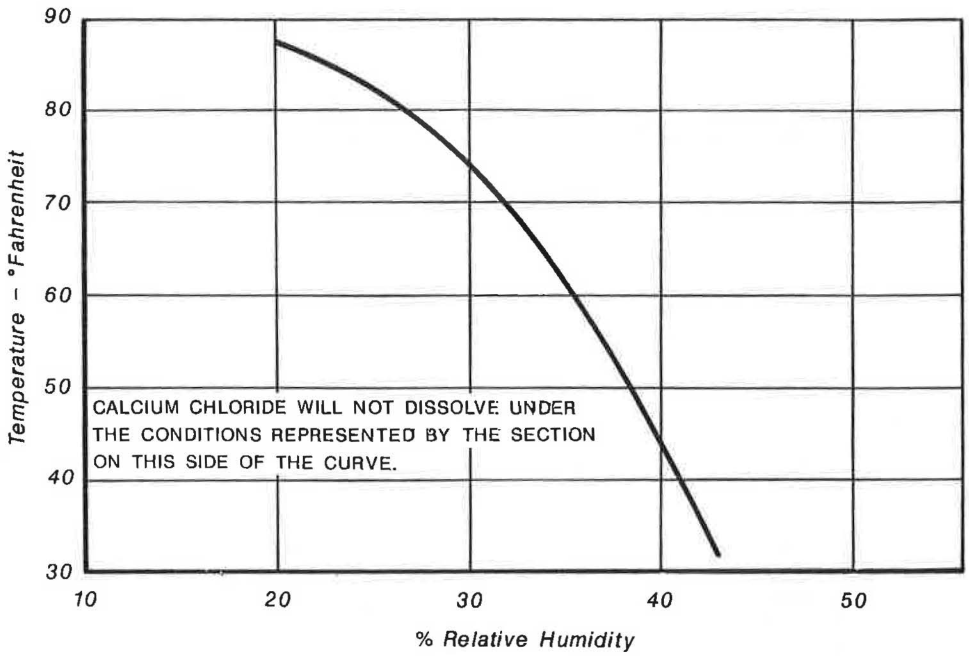

FIGURE 1 **Conditions for deliquescence of calcium chloride.**

TABLE 1 HYGROSCOPICITY OF CALCIUM CHLORIDE SOLUTIONS

RELATIVE HUMIDITY %	WATER ABSORBED BY ONE POUND OF CALCIUM CHLORIDE POUNDS	STRENGTH OF FINAL SOLUTION OF CALCIUM CHLORIDE %	VAPOR PRESSURE OF FINAL SOLUTION OF CALCIUM CHLORIDE mm OF Hg
95	8.2	8.5	22.2
90	4.5	14.5	21.0
85	3.3	18.3	20.3
80	2.5	22.0	18.9
75	2.1	25.0	17.5
70	1.8	27.5	16.6
65	1.6	29.8	15.5
60	1.4	32.0	14.0
55	1.3	34.0	12.7
50	1.2	36.0	11.8
45	1.1	37.9	10.5
40	1.0	39.9	9.5
35	0.9	42.1	8.5
30	0.8	44.5	

(Atmospheric humidities in equilibrium with Calcium Chloride solutions at 77°

NOTE: At 77°F the vapor pressure of pure water is 23.8 mm of Hg and it
tension is 71.9 dynes per cm^2.

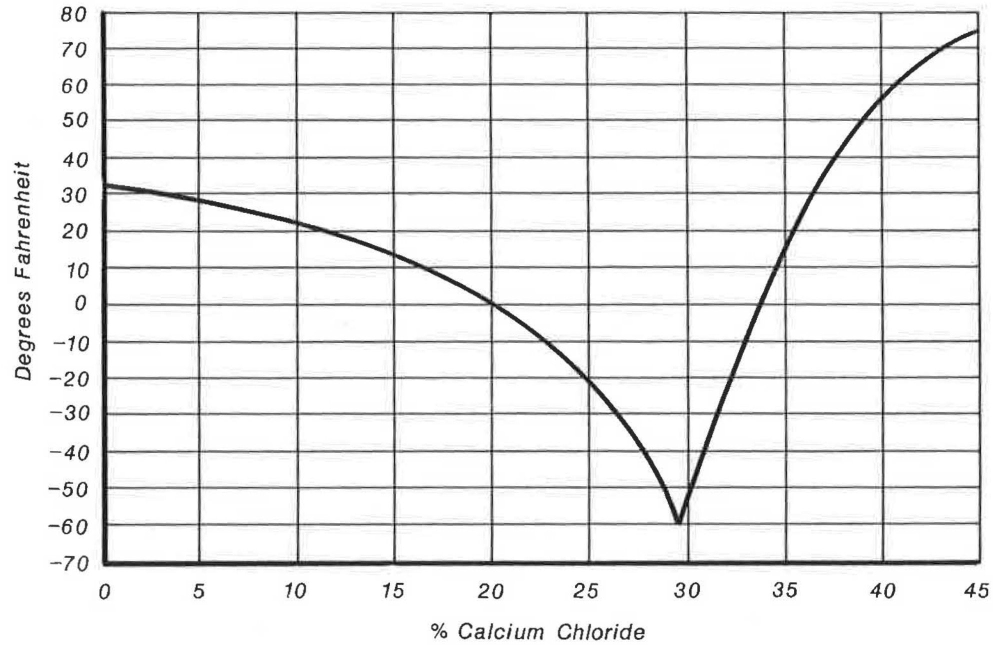

FIGURE 2 Ice saturation and apparent solidification of commercial calcium chloride solutions.

isting road conditions and determining the desired project requirements. Content and thickness of the existing asphalt structure and base material, in concrete with load requirements, will dictate the type and amount of any additives necessary to obtain the highest structural value for the investment. The depth of the bituminous surface must be checked to determine the design depth of pulverization. On the basis of these results, the engineer may choose the correct process for the given road conditions, thus allowing a contractor to select the proper equipment to accomplish the job.

The process of full-depth reclamation involves preparation of existing road material, including full-depth pulverization and mixing of asphalt pavement and granular base material. Pulverization is a mechanical process that physically breaks and crushes the asphalt pavement and a portion of the underlying base material to a suitable gradation. The pulverized asphalt cement acts as a binder in the base material, producing a stronger, homogeneous base that will support heavier loads. The design depth of pulverization is usually taken as twice the depth of the bituminous surface layer (approximately 8 in.). A pulverized bituminous layer blended with granular base material distinguishes full-depth reclamation from cold in-place recycling.

The pulverization process is performed by reclaiming machines, pulvimixers, stabilizers, or crushing units. These machines provide gradation and mixing requirements in one or two passes. These machines are self-propelled and usually consist of a rotating cutter mandrel equipped with carbide-tipped teeth. The unit breaks up existing asphalt pavement, while simultaneously pulverizing and blending it with the gravel base material. After pulverization is complete, excess material may be removed and redistributed or additional aggregate of proper gradation added depending on project requirements and design specifications.

With pulverization complete to proper gradation, additives such as liquid calcium chloride, asphalt emulsions, cement, or lime may be added to the reconstructed base to obtain longer-term performance. When calcium chloride is used as an additive, the aggregate mass is pulverized as required to thoroughly mix all materials and to meet the following gradation requirements:

U.S. Sieve Designation	*Openings (in.)*	*Percent by Weight Passing*
2 in.	2.00	100
1 in.	1.00	30–65
No. 200	0.0029	3–12

The total recommended amount of 35 percent liquid calcium chloride to be used is 1 gal/yd^2 (4.70 lb/yd^2) of road surface. The first application of 35 percent liquid calcium chloride is applied after the first pulverization at a rate of 0.75 gal/yd^2 (3.60 lb/yd^2) of road surface. The aggregate is then pulverized a second time to ensure proper gradation and mixing of the asphalt, gravel, and calcium chloride. A thorough mixing of calcium chloride is essential. After the materials are shaped, graded, and compacted, the existing base is sealed with 0.25 gal/yd^2 (1.10 lb/yd^2) of 35 percent liquid calcium chloride.

The stabilization effect of the calcium chloride is sufficiently immediate and the use of this process is for low-volume roads. The resultant surface may be opened to speed-controlled traffic, if required, without experiencing excessive wear or deterioration. The base course with calcium chloride should be allowed to cure for several weeks before construction of the final wearing surface. The length of time necessary for proper curing of the base course is dependent on climatic conditions of humidity and rainfall.

In order to achieve long-lasting results, a wearing course should be set on top of the base. Depending on traffic load, this wearing surface may consist of a single- or double-seal coat, cold mix, or varying thicknesses of asphalt cement.

FIELD TRIAL DESCRIPTION

Studies and tests of full-depth reclamation with and without calcium chloride base stabilization were conducted. The objectives of the case study (*1*) were to determine the effects of full-depth reclamation with calcium chloride stabilization on a low-volume road pavement structure. Data were acquired on both a stabilized test section and a control section.

The town of Caledon, Ontario, 10 mi north of Toronto, defined the study section of the Chinguacousy Road to be in need of base stabilization to remedy known structural deficiencies. The Chinguacousy Road is a rural two-lane roadway. Over the years, the study section had undergone surface treatment and hot-mix asphalt patching to maintain a dust-free trafficable surface. The study section on Chinguacousy Road was selected on the basis of the relative uniformity of the bituminous surfacing thickness and the granular material type.

The test area was divided into two 500-ft-long sections with an intermediate buffer area 65 ft in length dividing the two sections. Figure 3 shows this area.

The pavement conditions before reconstruction were determined by sampling through test pits. These conditions are described with respect to subgrade soil type, granular quality, and bituminous surfacing.

The subgrade soil, clayey silt to silty clay till, is part of the Halton Peel till stratigraphic unit. The liquid and plastic limits were determined to be 30 and 17 percent, respectively. The classification of the subgrade soil is A–2–6 in the AASHTO classification system and SC in the unified classification system.

The granular layer is a mixture of sand and gravel, composed primarily of hard carbonates. Gradation of the granular layer is presented in Table 2. Residual chloride levels (buildup from winter salting operations) were in the range of 850 to 910 ppm at depths from 3.20 to 6.0 in. in the pavement. Granular thickness of the base course varied between 8.0 and 12.0 in.; the granular thickness of the subbase course was irregular and not present in several areas.

The bituminous surfacing consisted primarily of a heterogeneous mixture of hot-mix asphalt and surface treatment. It

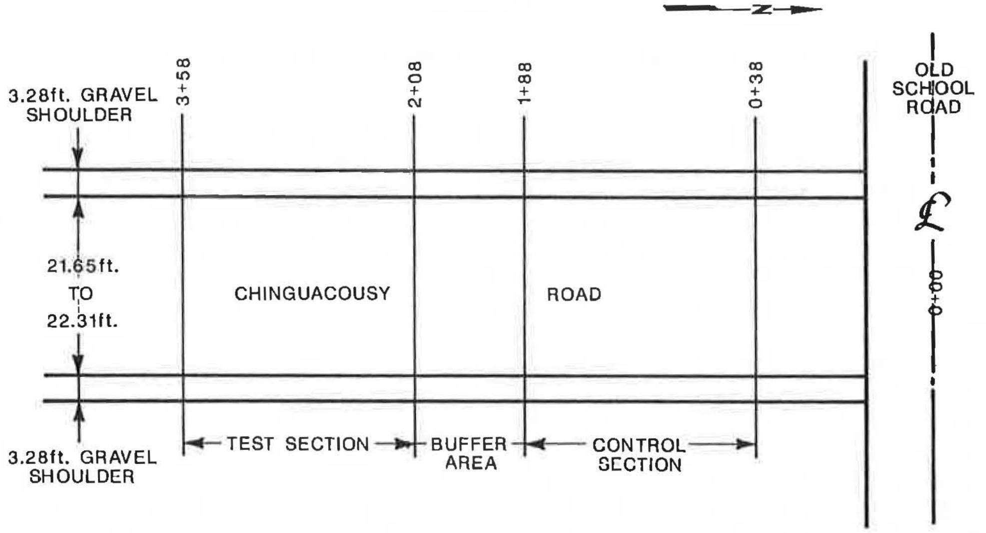

FIGURE 3 Test site diagram for Chinguacousy Road, Caledon, Ontario.

TABLE 2 BASE COURSE GRADATION ON CHINGUACOUSY ROAD, CALEDON, ONTARIO

		Percent By Weight Passing			
U.S. Sieve Designation	Opening (inches)	Granular Base Before Pulverization Test Area 1	Granular Base Before Pulverization Test Area 2	Granular Base Before Pulverization Test Area 3	Granular Base After Pulverization Test Area 4
1 Inch	1.00	100	100	100	100
3/4 Inch	0.75	97	100	99	100
Number 10	0.0787	43	20	34	30
Number 40	0.0165	21	12	17	13
Number 200	0.0029	7	7	7	6

had a fairly uniform thickness of 2.4 to 3.2 in. throughout. The average asphalt content was found to be 5.1 percent with an average asphalt penetration of 22.

The study section of the Chinguacousy Road was reconstructed by the process of full-depth reclamation. Both the control section and the test section were treated with the same equipment, materials, and procedures. The only difference in construction was application of calcium chloride to the granular base of the test section.

The existing bituminous surface layer was pulverized and blended with the underlying granular base to a design depth of approximately 6 in. using one pass of a reclaiming machine. The machine traveled at a speed of 55 ft/min and produced an average aggregate top size of 0.75 in. The exposed aggregate was then graded for full road width to restore crossfall. Additional imported sand and gravel granular base course was placed on the test and control sections using end-dump and belly-dump methods. Water was applied using a tanker truck with a spray bar attachment to achieve suitable moisture conditions. The total average additional granular thickness was approximately 2 in. after grading and shaping. Liquid calcium chloride (35 weight percent solution) was applied at a rate of 80 gal/yd^2 (3.80 lb/yd^2) to the graded granular base of the test section. This application represents approximately 1.0 percent calcium chloride by weight of dry aggregate for a 6-in. layer thickness. The loose granular was mixed with a reclaiming pulvimixer with one pass, and then graded and shaped. A single steel drum vibratory compactor compacted the loose granular. A final application of liquid calcium chloride was made at a rate of 0.20 gal/yd^2 (0.90 lb/yd^2). After curing from August 11 to August 29, 1989, the road surface was double surface treated with stone chips and emulsion.

A residual chloride test from October 1989 on granular samples obtained from test pits indicated that the effective depth of the calcium chloride was approximately 6 in. A visual inspection of the test pits under in situ granular conditions found a comparatively greater moisture content and darker color to a depth of approximately 6 in. Residual chloride data from October 1989 are presented in Table 3.

Nuclear compaction tests on the granular base material were taken both in the control and test section on August 29, 1989, just before the application of the surface treatment by the town of Caledon. Compaction results indicate that the average percent compaction on both sections was 98 percent standard Proctor maximum dry density (SPMDD) with a range of 94 to 100 percent SPMDD in the test section and 96 to 100 percent SPMDD in the control section. The results are based on an average SPMDD of the pulverized and blended granular of 138 lb/ft^3.

FIELD TRIAL RESULTS

Falling weight deflectometer (FWD) testing was carried out in August 1989, October 1989, April 1990, and August 1990. The FWD is a nondestructive testing device that imparts a dynamic load impulse to the pavement surface similar to a moving vehicle. The deflection response of the pavement to the applied loads is measured by seven seismic transducers. At Chinguacousy Road, FWD testing was undertaken in the outer wheelpath of the north- and southbound lanes at a spacing of 33 ft. The applied load magnitudes of the north- and southbound lanes were 6,000, 9,000, and 12,000 lb.

The FWD center deflections, normalized to 9,000 lb and 70°F, which are a measure of the overall composite strength of the pavement (including subgrade soil) immediately under the loading point, are presented in Table 4. The data indicate a relative increase in pavement strength of 3.4 to 15.1 percent in the test section as compared with the control section over 12 months. April 1990 FWD results indicate a decrease in pavement strength both in the test and control sections with the test section exhibiting a lower loss. Seasonal variability of road strength is a well-known phenomenon. As shown

TABLE 3 RESIDUAL CHLORIDE ON CHINGUACOUSY ROAD, CALEDON, ONTARIO

Sample Depth (inches)	Sample Location and Chloride Concentration in ppm			
	Borehole 6 Before Stabilization	Borehole 7 Before Stabilization	Saw-Cut #1 (Test Section) (1)	Saw-Cut #3 (Control Section) (1)
0 to 3	- (2)	-	2090	730
3 to 6	910 (3)	850 (3)	1160	460
6 to 8	-	-	620	590
8 to 12	-	-	460	440

(1) Test data from samples obtained approximately two months after Calcium Chloride stabilization.

(2) - Indicates Area Untested

(3) Test data represent benchmark chloride concentrations in original pavement structure before stabilization.

TABLE 4 SUMMARY OF FWD-NORMALIZED CENTER DEFLECTIONS

Section	Initial Mean Deflection August, 1989 (inches)	Mean Deflection October, 1989 (inches)	Mean Deflection April, 1990 (inches)	Mean Deflection August, 1990 (inches)	Percent Reduction In Deflection (12 Months)
Test Section					
Northbound Lane	0.052	0.035	0.059	.033	36.5%
Southbound Lane	0.049	0.035	0.052	.033	32.7%
					34.6%
Control Section					
Northbound Lane	0.042	0.033	0.050	.033	21.4%
Southbound Lane	0.041	0.031	0.047	.029	29.3%
					25.4%

in Figure 4, the strength loss in April 1990 is an expected result (*2*).

The calculated deflection basin areas, as defined by Hoffman and Thompson (*3*), are presented in Table 5. The basin area is a measure of the ability of the pavement to distribute an applied load. In general, the magnitudes of the basin areas tend to be higher as pavement load distribution improves. Table 5 indicates an overall increase of approximately 2 percent in the calcium chloride–stabilized test section versus the untreated control section over the 12-month period. Once again, the expected seasonal impact can be noted when comparing results from April 1990 to October 1989 or August 1990.

Resilient moduli tests were performed on both the calcium chloride–treated granular and untreated granular samples that were recovered from the on-site pulverization and mixing process. The resilient moduli testing was carried out using closed-loop electrohydraulic MTS equipment at McMaster University, Hamilton, Ontario. Testing was based on the interim SHRP protocol (*4*,p.46), with some modifications to the preparation of granular test specimens. The samples were prepared at 100 percent standard Proctor density and were frozen to facilitate handling and setup in the MTS triaxial cell unit. A load duration of 0.1 sec and a cycle duration of 1 sec were used with a haversine stressed pulse. The resilient modulus is a measure of the applied axial stress over the recover-

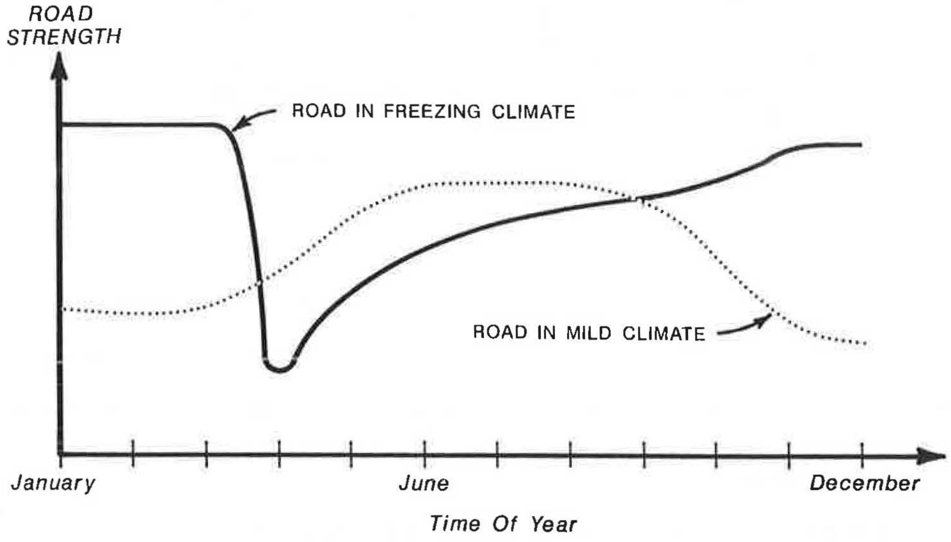

FIGURE 4 Seasonal variability of road strength.

TABLE 5 SUMMARY OF FWD BASIN AREAS

Section	Initial Mean Deflection August, 1989 (inches)	Mean Deflection October, 1989 (inches)	Mean Deflection April, 1990 (inches)	Mean Deflection August, 1990 (inches)	Percent Increase In Deflection (12 Months)
<u>Test Section</u>					
Northbound Lane	0.0165	0.0189	0.0177	0.0185	12.1%
Southbound Lane	0.0173	0.0193	0.0185	0.0185	6.9%
					9.5%
<u>Control Section</u>					
Northbound Lane	0.0173	0.0189	0.0177	0.0188	8.7%
Southbound Lane	0.0173	0.0189	0.0177	0.0185	6.9%
					7.8%

able strain for given magnitudes of load, load duration, and bulk stress conditions. Test results from Table 6 show that the calcium chloride–stabilized granular has a 24 to 36 percent higher modulus than untreated material for conditions of low bulk stress. The moduli of the stabilized and nonstabilized material are similar at higher bulk stress conditions.

Slate's work states that there is reduced freeze-thaw susceptibility of materials treated with calcium chloride and that there is satisfactory long-term retention of calcium chloride in the pavement structure. Samples treated with 1.0 percent calcium chloride by weight of dry aggregate may experience 50 to 60 percent reduced frost heaving, compared to untreated samples (*5*).

Residual chloride testing was conducted on the test section of the Chinguacousy Road in August 1990. Samples were analyzed from the edge and center of the road at depths

TABLE 6 SUMMARY OF RESILIENT MODULI TEST RESULTS

Test Load (Cell Pressure = 3 psi)	Resilient Modulus (psi)		
	Sample A (not stabilized)	Sample B (stabilized)	Sample C (stabilized)
Load = 55 pounds	59,600	81,400	74,300
Load = 90 pounds	35,000	34,600	40,600
Load = 128 pounds	24,700	22,100	26,100

NOTES:
1) Loading duration was 0.1 seconds with a cycle duration of 1 second and a haversine-shaped stress pulse

2) Stabilized samples treated with 1.0 percent $CaCl_2$ by dry weight of aggregate

3) All samples prepared at 100 percent Standard Proctor Density and approximately 7 percent moisture content

TABLE 7 RESIDUAL CHLORIDE ON TEST SECTION OF CHINGUACOUSY ROAD, CALEDON, ONTARIO, AUGUST 1990 (PARTS PER MILLION)

Sample Depth (inches)	Before Stabilization	October,1989 Test Section	August,1990 Test Section Center of Road	August,1990 Test Section West Edge
0 - 3	- (1)	2090	3690	2250
3 - 6	910 (2)	1160	2620	2140
6 - 8	-	620	1260	1960
10 - 12	-	460	639	1820
12 - 18	-	-	496	1860
18 - 24	-	-	933	1540
24 - 30	-	-	541	1190
30 - 36	-	-	326	809
36 - 42	-	-	320	532

(1) Indicates area untested

(2) Test data represent benchmark chloride concentrations in original pavement structure before stabilization

varying from 0 to 42 in. Table 7 indicates that the calcium chloride has been retained in the road structure over the 12-month period.

Visual condition surveys conducted August 1989, October 1989, January 1990, April 1990, and August, 1990 had good cross-sectional properties and no potholes in both sections.

CONCLUSION

Calcium chloride addition to the full-depth reclamation process provides an optimized maintenance procedure for low-volume roads in geographic areas where humidity and soil clay content support calcium chloride use. Data presented consistently indicate road strength has been improved in the test section using calcium chloride addition versus the control section with no additive.

Resilient moduli testing indicates an increase in strength (modulus) in the calcium chloride–stabilized section over the untreated granular section in the range of 24 to 36 percent at conditions of low bulk stress. Normalized FWD deflections indicate an in-place overall pavement strength increase in the test section compared to the control section was 3.4 to 15.1 percent over a 12-month period. Both the test and control section incurred a strength loss in April 1990, with the test section exhibiting a lower percentage loss from original values. These results reflect moisture retention (hygroscopic) properties of calcium chloride.

Residual chloride testing 12 months after application indicates retention of calcium chloride in the test section has been excellent. Previous studies (*6*) indicate satisfactory long-term retention of calcium chloride in pavement structures can be expected. Reduced freeze-thaw susceptibility is also indicated.

The analysis of AASHTO design methods for low-volume aggregate-surfaced roads given in the *AASHTO Guide for Design of Pavement Structure* (*7*) indicates that for the Chinguacousy Road test section the strength improvement in the granular base layer because of calcium chloride stabilization should result in an increase in allowable standard-axle traffic loadings of 40 to 50 percent, or an increased pavement life of 3 to 5 years.

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