Liquid Treatments of Commercial $CaCl_2$ in Winter Road Maintenance

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This paper describes 2 experiments using liquid solutions of a commercial calcium chloride type 77-80, on Highway 26 and Highway 26 express from the Mont Blanc Tunnel in the Aosta Valley and on Highway 242 to Gardena Valley on the occasion of the 1970 Mondial Ski Championship. These experiments were preceded by a meteorologic study, in which the road was divided into 3 parts corresponding to 3 different altimetrical belts from some hundreds of meters to 1,400 m elevation at the entrance of the Tunnel on the Italian side. The total annual average snowfall forecast was 170 cm. For one experiment, a 15-km section was chosen between the Tunnel and Morgex where, even if the slope is not excessive, cars must have chains or camion tires. The amounts used were of 10 gr/m^2 in the preventive treatments and 40 gr/m^2 in the maintenance treatments. The numerical ratio among these types of treatments was, on the average, 1 to 3. Also described is the Gardena Valley experiment and the modifications made to the equipment.

In the last few years the problem of road safety has assumed a great importance on account of the number of accidents, often fatal, occurring on our roads. Motorization, developing itself much faster than the road network is being adapted and improved, contributes together with the increase in the traffic density to make roads less and less safe.

One aspect of traffic safety, which has not been taken into proper consideration, is the elimination or reduction of accidents due to snow or ice on the road. During the clearing operation, the machines do not perfectly clean the road, and complementary operations are required to remove the residual snow or ice layers. These operations sometimes account for 50 percent of the total cost of the clearing operation. They involve the spreading of salty materials that induce the melting of the packed or frozen snow layers that the snowplows fail to remove. The same materials are efficiently used for removal of glaze and for preventive treatments. The widespread use of the salts, particularly NaCl (sea or rock salt) and $CaCl_2$, has given rise to a series of new problems and questions that require definitions of the effective possibilities, the limit of use, and the working characteristics of the materials used. Above all it is necessary to clarify the true dynamics of the process of elimination of ice or snow treated with salts, which appears as a melting process.

A dry NaCl grain or a dry $CaCl_2$ flake has no direct melting action, and if the air moisture is low, under 40 percent for $CaCl_2$ and at least 70 percent for NaCl, the salt grains remain inert as if they were stone, grit, or sand. The melting only occurs after the salt is dissolved and has formed a solution by taking the moisture from the atmosphere or from the icy layers to be treated. Therefore the efficiency of the grain or flake salts in the preventive applications depends on the vapor content of the atmosphere.

Since the winter of 1965, the use of calcium chloride solutions has been extended, especially on an experimental scale, although the adoption of this technique obviously requires special equipment and the employment of trained specialized labor.

On this point it is necessary to examine the elements that influence the choice between the use of salts and the use of salt solutions. The technique adopted will be influenced by the thickness of the icy layers to be treated and the ambient moisture. The temperature, although it indicates the most convenient type of salt to be used, is not a determinant, especially between certain limits, in the choice of whether the solid or liquid is most advisable.

For thin icy layers, the use of more or less coarse grains may have an influence on the velocity of the melting action, which reaches the highest values when the grains are of a size near that of the layer thickness. For still thinner layers, an excessive grain size will have a negative influence. Generally it may be said that for the removal of a thin layer of snow, small grains are necessary; but for a thicker layer, large grains are required.

Grains smaller than $\frac{1}{32}$ cu in. (0.5 cm^3 corresponding to a sphere with a 2.3-mm radius) have a too rapid superficial dissolution effect and a reduced penetration. To obtain the best result in removing an icy layer requires that the grains completely penetrate to the pavement and be adjusted such that the ice is prevented from sticking to the road. The very small grains penetrate faster but are used up before reaching the pavement. According to Kaufman, the ideal would be represented by a very well-graded mixture with sizes passing and retained by the No. 3 and No. 12 sieves of the Tyler series (from 7 to 2 mm approximately).

In addition to the size of the grain, the penetration is also influenced by the thickness and by the temperature. An explanation of this fact is given by a simple consideration of the grain's specific surface. Suppose we use grains with a spherical form. The ratio of surface to volume is given by

$$\frac{4\pi R^2}{\frac{4}{3}\pi R^3} = \frac{3}{R} = \frac{6}{d}$$

This means that the smaller the grains, the larger the total surface and the greater the possibilities of contact with the icy layer will be.

Regarding moisture, according to a survey made by the Ohio State University, sodium chloride is able to absorb easily atmosphere moisture when the moisture content is very high, higher than 70 percent and generally between 75 and 100 percent, whereas the calcium chloride can absorb moisture when the content is much lower, generally between 40 and 50 percent at a temperature between 0 and -26 C. For moisture values lower than these, the use of both these salts would not be effective.

Eliminating icy layers of the glaze type, i.e., very thin layers of frozen humidity or water, by using anhydrous salts is very difficult for the reasons already given on the relation between thicknesses of the ice and diameter of the salt grains. Therefore the solid treatment has dubious utility. Problems with this treatment include the difficulty of "starting," the salts' solubility under low moisture conditions, and the decrease in the salts' action in relation to the thickness of ice to be treated. In addition there is the frequent breakdown of the spreading machines due to caking of the grains or flakes of salt as well as the waste caused by the salt being scattered by the traffic. In the successive checkings, it is almost impossible to obtain a reliable evaluation of the effectiveness of using the solid material. This doubt has led to repeating superfluous or excessive treatments with increased costs of operation.

For these reasons experiments were carried out during the 1965-1966 winter season by the Azienda Nazionale Autonoma Delle Strade (ANAS) on the use of saline solutions.

The use of the solutions makes it possible to eliminate the disadvantages of the solids, i.e., the difficulty of starting, the solubilizing of the salt under low moisture conditions, and the decrease in the salt action in relation to the thicknesses of ice to be treated. The solutions eliminate the time taken by the salt grains to dissolve and the possibility of failure in starting due to scarce atmospheric moisture; develop a faster action owing to the larger surface of contact between solution and icy layer; ensure an even melting, or at least a road surface evenly prepared because the solution can be spread with fairly good continuity; eliminate the possibility of caking of the grains in the spreading machine, especially when the latter has been loaded in advance and is left waiting; and make it possible to check the residual strength of the solution spread on the road, even after some days.

Having decided to use solutions, we selected calcium chloride instead of sodium chloride for 2 reasons: (a) The eutectic obtained is much "lower" than that obtained with NaCl; and (b) the solubility of $CaCl_2$ in water is facilitated by its exothermic characteristic. When hydrating it gives off considerable heat. On the other hand, NaCl when dissolving absorbs heat from the water and consequently becomes colder and delays the dissolving process.

PROPERTIES OF THE CALCIUM CHLORIDE SOLUTION

Calcium chloride is very soluble in water. Both anhydrous and hydrated (commercial type 77-80 contains approximately 20 percent water), it is hygroscopic, i.e., capable of absorbing the moisture of the atmosphere or of the icy layer by partially or totally dissolving in relation to the ambient vapor pressure and temperature.

The mechanism followed is the same for both the solids and the solutions. These can also absorb the ambient moisture until an equilibrium is established, which is a function of the atmospheric vapor pressure in relation to the temperature. In particular, with the solutions it may occur as both a dilution and a concentration.

This relative instability is obviated by preparing solutions of medium high strength and by checking them later by means of special reagents. In every case, except in very special cases, which will be indicated in the following, the difference in the ambient vapor pressure/solution is not such as to modify substantially the strength of the prepared solution, which varies around mean values corresponding to the forecasts.

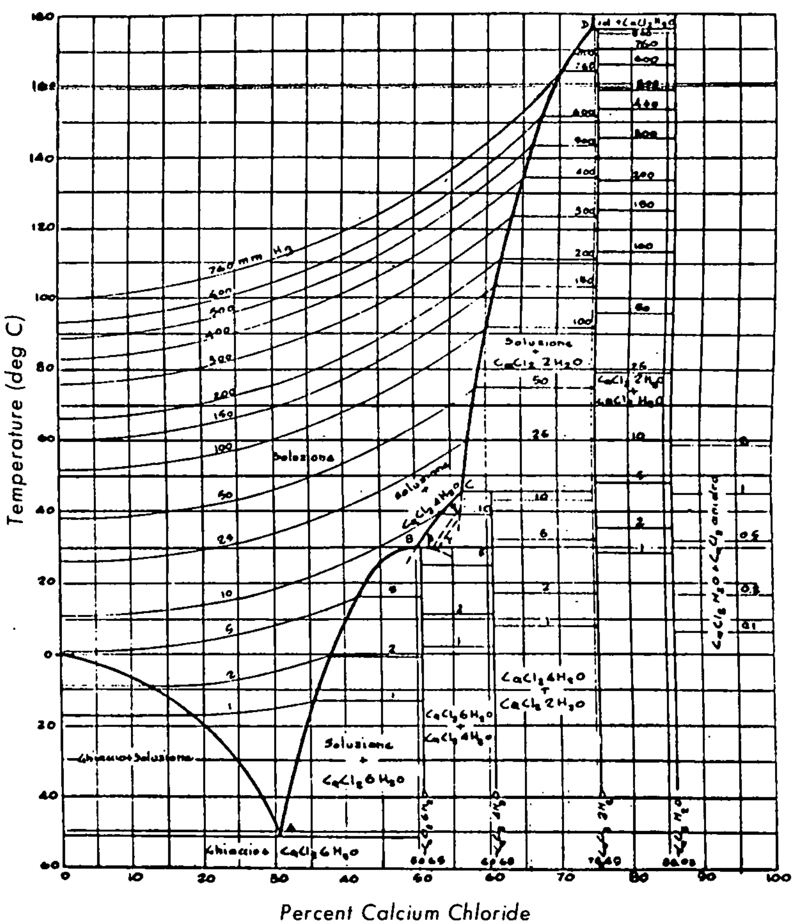

Figure 1. Phase diagram and vapor pressure of the system $CaCl_2$-H_2O.

The solubility data are given in Figure 1. The figure shows the curve of solubility in water of $CaCl_2$ as a function of concentration and temperature. In the upper part above this curve is the area of the unsaturated solutions where the product is thoroughly soluble. Under the curve is the area of coexistence of the saturated solutions equilibrated with ice or solid hydrates as well as mixtures of wholly solid hydrates. Although data for pure $CaCl_2$ are shown in the figure, it is sufficiently valid at least for ordinary uses and also for the use of the commercial product 77-80 in winter.

For preparing the solutions, data shown in this diagram give an indicative value of the concentrations to be used in relation to ambient temperature. It should be kept in mind, however, that this concentration is to be corrected in relation to the prevailing temperature, taking into account the limits of the future use. In other words, to prepare a 20 percent solution with a freezing point of approximately -18 C in an atmosphere at temperature of 0 C, one must "correct" the reading of the densimeter by a certain value by using a table of data determined with a densimeter and a pycnometer set for a temperature of 15.5 C (International Critical Tables).

PREPARATION OF THE SOLUTIONS

Calcium chloride type 77-80 is offered for sale in PVC bags, each containing 50 kg. This salt is a by-product of the industrial production of soda (following the well-known Solvay process) and therefore it is already in a liquid condition. This is helpful if the solutions are used on a large scale.

The choice of the concentration of $CaCl_2$ in the solution depends on the type of treatment, preventive or curative, to be carried out as well as on the ambient atmospheric conditions during the application. According to the experiments carried out, it is advisable to use the following $CaCl_2$ concentrations for the different types of applications: 15 percent for preventive treatments (temperature at which the first ice crystals appear, -10.3 C); and 26 percent for curative treatments (temperature at which the first ice crystals appear, -32.5 C).

Each 250 kg of $CaCl_2$ (5 bags) added to 1,000 liters of water gives approximately 1,100 liters of 15.6 percent solution. Each 500 kg of $CaCl_2$ (10 bags) added to 1,000 liters of water gives 1,200 liters of a 26 percent solution. The 15 percent solution can also be obtained by diluting the 26 percent solution by an equal volume of water.

The solution is prepared as follows:

1. Fill the dissolving container with the amount of water necessary for preparing the solution, the strength of which is given.
2. Pour the chloride in the container, keeping the water agitated by means of a special apparatus. For this operation it is advisable to pour the material gradually in order to prevent the flakes from agglomerating in a mass on the bottom of the tank and dissolving with much difficulty.
3. Keep the whole mass moving to obtain a homogeneous solution without any solid residue.

Because $CaCl_2$ is exothermic, during the phase of the dissolution of chloride in water a considerable amount of heat is evolved, which increases solubility. The order of magnitude of this heat evolution can be appreciated by noting that in the preparation of a 25 percent solution the temperature of water increased by approximately 33 C.

EFFECTIVE USES OF CALCIUM CHLORIDE SOLUTIONS

The calcium chloride solutions may be effectively used in the following cases.

Preventive Applications

The solutions prevent the formation of icy layers (glaze) on the bare pavement due to (a) an ambient temperature of approximately 0 C with a tendency to go down with nebulous formation in the air and humidity close to saturation point (the fall in temperature makes for precipitation of icy particles, which agglomerate and form a continuous frozen surface); and (b) the pavement of the road being wet with rain and the temperature of the surface being about 1 to 2 C above zero. The wind causes the water to evaporate and, consequently, takes the heat from the pavement. Even if the ambient temperature is 1 to 2 C, the water layer freezes promptly. The solutions also prevent the snow from sticking to the pavement.

Maintenance or Curative Applications

By annihilating the cohering action of the snow mass, the solutions fluidify the layers of hard or packed snow, provided they are not completely frozen. The solutions can be applied for eliminating either the snow layers remaining after passing of the snowplows or the fresh snow layers, provided they are of moderate thickness (about 10 cm).

The suggested amounts of 15 and 26 percent solutions are given in Table 1. With these amounts, a 10-m^3 tank can provide preventive treatment of a 220,000-m^2 road surface with 26 percent solution and maintenance treatment of a 100,000-m^2 road surface with 26 percent solution. Therefore, a road with an average width of 5 m can be spread for a distance of 44 and 20 km respectively.

THE MONT BLANC TEST

During the winter of 1965-1966, the department in Turin decided, in agreement with ANAS, to conduct a series of experimental maintenance operations using calcium chloride, commercial grade 77-80, in aqueous solution.

Mont Blanc Tunnel had opened in July 1965 and was expected to have heavy traffic even in winter because of the tourist traffic through Courmayeur and Chamonix. Consequently, it was necessary to study problems connected with winter travel on Highways 26 and 26 express.

At a preliminary stage, the road section to be used in the experiment was delimited by a study of the meteorological features of the district, aiming principally at determining the magnitude and the variability temperature and local humidity as well as the volume of precipitation. In this research, data of the Ministry of Works, the Meteorological Department of the Air Service, the Italian Committee for Glaciology as well as from various special studies were examined. Some of the findings are given in Table 2.

Precipitation was subdivided into the following classes of snowfall for various sections:

Section	Length (km)	Mean (cm)	Maximum (cm)
Tunnel to Pré Saint Didier	11	110	170
Pré Saint Didier to Aosta	32	40	80
Aosta to Quincinetto	58	20	50

This subdivision corresponded to the subdivision in altimetrical zones—0 to 500 m, flat land; 500 to 1,000 m, low mountainous area; and 1,000 to 1,400 m, mountainous zone—which indeed was sufficiently representative of the variability of precipitation and of the number of days of frost according to the altitude level. Based on this subdivision, it has been possible to compare the snow precipitation during the years 1959 and 1960 for the 3 sections. This comparison is given in Table 3.

In consequence of this, it was decided that the experimental section would be between the entrance of the gallery situated after the customs place at the Tunnel and the locality of Morgex, along Highway 26 express in the direction of Aosta (Fig. 2).

TABLE 1

SUGGESTED AMOUNTS OF CALCIUM CHLORIDE

Calcium Chloride	Preventive	Maintenance
Solution		
15 percent, g/m^2	50	210
26 percent, g/m^2	30	120
15 percent, cc/m^2	45	185
15 percent, cc/m^2	25	100
Flake, g/m^2	10	40

TABLE 2

TEMPERATURE AND RELATIVE HUMIDITY IN RESORT OF AOSTA

Month	No. of Days With Temperature Below 0 C	Temperature		Percent Relative Humidity	
		Mean	Extreme	7 a.m.	10 p.m.
January	23	-2.4	-12.2	70	62
February	18	-1.7	-12.0	71	55
March	10	+1.4	-12.0	71	50
April	2	+5.3	-4.2	73	45
May	—	+8.7	0	78	49
October	1	+6.3	-3.2	83	57
November	7	+2.0	-8.2	73	60
December	19	-1.1	-9.4	70	64
Total	80				

TABLE 3

NUMBER OF DAYS OF SNOWFALL ON 3 ROAD SECTIONS, 1955-1964

Section	Reference Stations	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964
Tunnel to Pré Saint Didier	Courmayeur	31	23	—	25	26	30	16	35	35	27
	Pré Saint Didier	—	—	—	—	—	—	—	—	—	—
	S. Nicolas	20	17	9	17	12	18	11	—	—	—
Pré Saint Didier to Aosta	Valgrisanche	34	41	28	36	43	47	24	45	43	28
	Rhemes N. Dame	—	—	—	—	—	39	16	44	36	35
	Rhemes S. Georges	42	24	20	29	29	29	16	28	21	25
Aosta to Quincinetto	Aosta	10	7	4	12	—	12	—	6	14	8

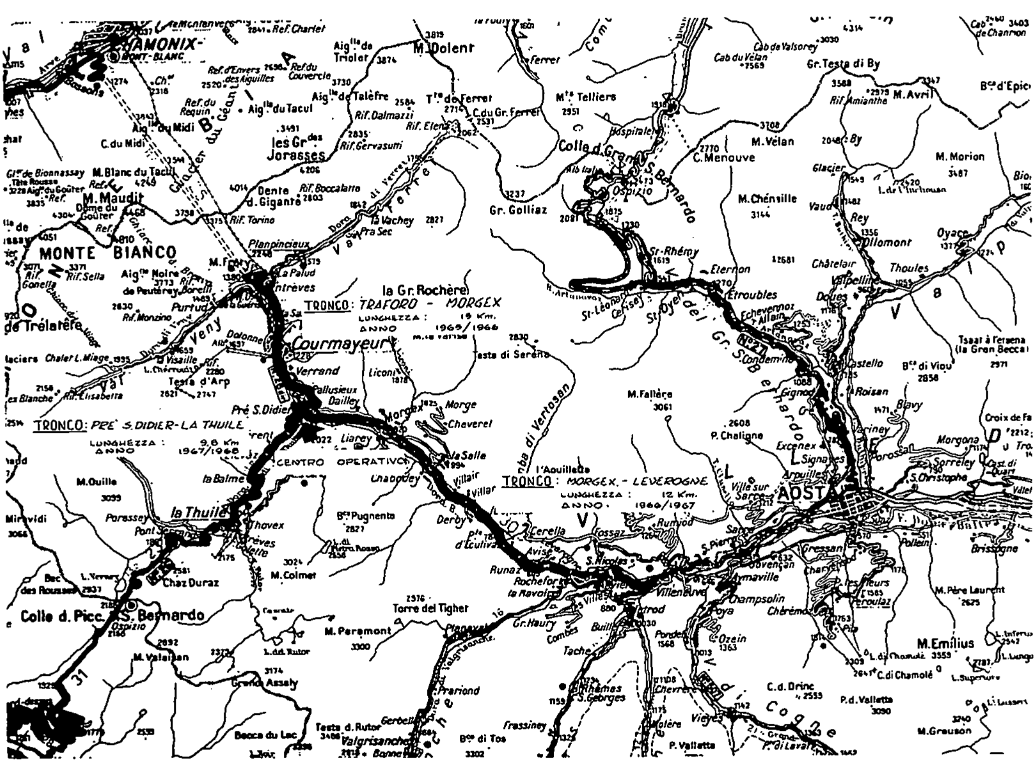

Figure 2. Location of experiment on 3 road sections from the Mont Blanc Tunnel.

In addition to meteorological reasons, this 15-km section was also recommended for other reasons.

From a technical point of view, there had to be the capability to completely treat both lanes at one time with both de-icing (curative) and preventive treatments. In addition there was the matter of moving traffic quickly and safely. It was observed that the altimetrical level features of the road undergo a considerable modification in this section. From 920 m at Morgex, the elevation rises to 1,381 m at the Tunnel entrance, with a mean grade of 3.20 percent. This slope is not exceedingly exacting for the motor freight car trains, which, according to spot checks, begin to put on their snowchains precisely in this section. Because we wanted to keep traffic moving and, consequently, avoid the concentration of the heavy transport vehicles, a considerable percentage of the total traffic, it was deemed useful to facilitate the traffic in this section to a maximum.

For economic reasons and also in view of the experimental nature of the operation, the maintenance operations were contracted to a firm already equipped with suitable machines. The contract work agreement, renewable from month to month, provided that an operating center should be installed in Pré Saint Didier in which the selection container of the chloride was to be set up. Moreover, it was prescribed that the tank should have a capacity of 10,000 to 12,000 kg, be mounted on a truck type 682 (or a similar type), and be fitted with junction pipes to 2 liquid sprinkling bars. These bars were to be made of bronze and fitted with 3 series of interchangeable nozzles in order to regulate the quantity of liquid to be spread on a width of 5.50 m of roadway. The liquid was to be supplied to the bars by means of 2 centrifugal pumps, driven by a 10-hp explosion engine or by the engine of the truck after the required modifications were made. The pressure at the nozzles was to be, in any case, higher than 3 atmospheres. The container was to possess a minimum capacity of 12 m^3 and be fitted with an electric agitator in order to speed up the solution of the calcium chloride in water. The contract did not include the supply of the calcium chloride (provided by the department) or the labor required for the solution preparation operations. It did provide that a specialized driver be permanently present on the working site for the duration of the agreement and be at the disposal of the personnel of ANAS on request, within 30 minutes at most. The monthly charge provided for 60 hours of tanker work, excluding the times for loading, as well as the occasional technical help from the specialized personnel of the supplier firm. Each hour of spreading work beyond the specified 60 hours was to be paid separately according to the provided scale. During the operations, this agreement remained almost unchanged, with the exception of the amount, which was reduced.

The operations included the following:

1. Preventive treatments—A 15 percent solution was prepared in about 20 minutes (temperature of appearance of the first crystals, -10.3 C) and the tanker, after having carried it (average time, 20 minutes), began the treatments in the direction of the Tunnel. The amounts of solution were fixed at 50 g/m^2, corresponding to 10 g/m^2 of solid material.

2. Maintenance treatments—A 26 percent solution was prepared in about 30 minutes (temperature of appearance of the first crystals, -32.5 C). The tanker was loaded in about 20 minutes. The amounts of solution were fixed at 120 g/m^2, corresponding to 40 g/m^2 of solid material.

Owing to necessities, 15 percent solutions were sometimes used for maintenance treatments and 26 percent solutions for preventive treatments. In the first case, the amounts rose to 210 g/m^2, corresponding to 40 g/m^2 for solid material; and, in the second case, they dropped to 30 g/m^2, corresponding to 10 g/m^2 of solid material.

The treatments with $CaCl_2$ solutions began on December 21, 1965; they were continued during the following days either by the preventive procedure or by the maintenance method according to the necessities.

Table 4 gives the data on snowfalls during the winters of 1965-66, 1966-67, and 1967-68. During 1965-66 treatments were limited to the 15-km section between Morgex and the Tunnel. In view of the satisfactory results obtained, the section was

TABLE 4

SNOWFALLS FROM 1956 TO 1968

Date	Number of Days	Depth of Snow (m)	Date	Number of Days	Depth of Snow (m)
1965-66	43	7.50	1966-67		
Nov. 15-21	6	1.25	Dec. 28	1	0.15
Nov. 24-30	7	1.55	Jan. 21-25	5	0.60
Dec. 2-6	5	0.65	Feb. 17-20	4	0.80
Dec. 10	1	0.35	Feb. 27	1	0.20
Dec. 21-31	11	1.50	March 18	1	0.20
Jan. 2-4	3	0.40	March 28	1	0.15
Jan. 11-12	2	0.35	1967-66	32	4.95
Jan. 21-24	4	0.75	Oct. 31	1	0.25
Feb. 17	1	0.20	Nov. 2-5	4	0.40
Feb. 21-22	2	0.20	Nov. 27	1	0.15
March 26	1	0.30	Dec. 26	1	0.15
1966-67	22	4.50	Jan. 1-2	2	0.35
Nov. 29-30	2	0.65	Jan. 4-14	15	2.05
Dec. 2	1	0.20	Jan. 18	1	0.10
Dec. 4	1	0.20	Feb. 6-10	5	0.90
Dec. 12-15	4	0.70	Feb. 20	1	0.35
Dec. 23	1	0.20	March 21	1	0.25

extended from Morgex to the south in 1966-67, a total of 25 km. In 1967-68 a section was extended from Pré Saint Didier to La Thuile, a total of 35 km (Fig. 1).

ECONOMIC VALUATIONS

During the first winter, frequent inspections were made to obtain operating and cost data.

The cost of salt materials, based on an average utilization of about 250 hr/yr and a mean value of the weight of fresh snow mass of about 100 kg/m^2, is as follows (1):

Materials	Time Work ¢/m^2	Contract Work ¢/m^2
NaCl	0.35	0.40
$CaCl_2$	0.34	0.33
Mixture 1:3 by weight	0.35	0.34

The analysis was made on the basis of the amounts required to melt snow layers about 5 cm thick at a temperature of -5 C. Table 5 gives a summary of the operations during the 3 winters. Average total costs of the contract work amounted to $960/mo. Average costs of the contract work and the material used amounted to 0.15 ¢/m^2. There was a wide range in actual costs, because in preventive treatments the amount of solid material used was 10 g/m^2, whereas in maintenance operations it was as high as 40 g/m^2.

The comparison between the mean costs of operations with solids and with liquids shows an average ratio of about 2 to 1. To appreciate this ratio, one should consider the following:

1. In the analyses of the costs of spreading solid salt materials, labor for loading the tanker was not taken into consideration. Similarly, labor for preparing the solution of the material in the container was not taken into consideration. In a first approach, the 2 items may be considered equivalent; however, according to a more accurate analysis, the economic comparison seems to favor the solutions because of the less amount of time required; 10 m^3 of a 26 percent calcium chloride solution can be prepared and loaded in the tank in about one hour on an average.

2. In the analyses of the costs of spreading solid salt materials, the amounts considered were those required for the complete melting of snow layers 5 cm deep at an

TABLE 5

SUMMARY OF OPERATIONS

Item	1965-66	1966-67	1967-68
Operations	37	42	35
November	—	2	2
December	7	17	7
January	21	16	15
February	9	7	11
March	—	—	—
Hours	89	141	128
November	—	7	5
December	20	69	28
January	48	37	58
February	21	28	37
March	—	—	—
Section length, km	15	25	35
Avg. speed of treatment, km/hr	6.2	6.4	9.6
Avg. width treated, m	6	6	6
Calcium chloride used, kg	80,000	120,000	160,000
Months of actual work	2	3	3
Surface treated per operation, m^2	90,000	150,000	190,000
Avg. amount per operation, g/m^2	24.0	22.2	21.8
Cost of contract work, $	1,920	2,880	2,880
Avg. cost of contract work and material used, ¢/m^2	0.16	0.15	0.13
Ratio of preventive to maintenance operations, percent	40-60	30-70	40-60

outside temperature of -5 C. These amounts were as follows:

Material	g/m^2
NaCl	175
$CaCl_2$	70
Mixture 1:3 by weight	120

These amounts, however, were appreciably higher than those anticipated for the treatments with liquids. Moreover, the specified amounts do not, of course, allow for the effects of the traffic, the time required for the melting, or possible favorable environmental conditions, as for instance the insulation of the sections treated. The currents of air produced by passing vehicles remove a certain part of the solid material, estimated conservatively at 10 percent, from the roadway. In preventive treatments, this phenomenon is intensified because the mass of granules thrown down by the oscillating device of the spreader on 1 m^2 is very small and, consequently, more easily moved by the traffic before it can be charged with humidity and adhere to the pavement.

Other causes include the turbulence of the spreader and the lack of uniformity in the distribution of the salt over the pavement. Moreover, in the operative phases of snow removal, it may happen that the alternation of the successive passes of plows and spreaders is not distributed over the time to make possible the complete action of the de-icing chemical still in the solid state. Therefore, the amount of salts actually utilized and, as a consequence, their efficiency are markedly reduced.

For these reasons, to obtain the same results in preventive treatment by using 10 grams of $CaCl_2$ in solution will require at least 20 gr/m^2 of solid material.

Finally, and especially in the case of preventive applications, the solid-liquid costs ratio seems actually to vary about a value of 2 to 1, whereas, with well-planned curative applications carried out under optimum conditions, this value could be lowered to about 1.5 or 1.2 to 1 as a result of better dispersion and of more complete utilization of the product.

Another important consideration in the cost analysis is that the use of solid material is under time work, whereas the use of solutions is under contract work. In the time work, vehicles are used on an average of about 250 hr/yr, whereas in contract work one has to consider the summer season. Because the major cost is that of labor (over 60 percent), a reduction in depreciation and overhead, which varies with the time of use, is offset by an increase in labor, which remains constant in value. Average costs for both time work and contract work were given earlier.

Operation Checks

During the years in which the tests were made, recrystallization of the chloride on the pavement due to evaporation of the solvent was observed. In order to exclude recrystallization of the salts, which would appear not in anhydrous or pulverulent form (as in the case of sodium chloride) but as a film of dense hydrate in a drying phase and therefore slippery, reagents that tend to ascertain the strength of the solution on the pavement were studied and prepared. It is thought that, because of the accumulation of calcium chloride after repeated treatments, the recrystallization might take place only with less than 45 percent of atmospheric humidity, strong wind, insolation, and a temperature of about 0 C.

Checking of concentration proved thus to be very advisable, especially in relation to the lingering of the solution on the pavement for several days after the treatment. Under conditions of normal humidity (60 percent), the liquid film remained on the pavement for 6 to 8 days and maintained an efficient concentration. It is recalled that for diluting a 26 percent solution to 15 percent requires that it absorb an amount of humidity almost equal to its own volume; and for attaining a strength of 5 percent, the solution has to absorb an amount of water equal to about 4 times its volume in relation to the starting solutions. The strength of the solution on the road is determined by spraying a few drops of a reagent on the pavement. The presence of $CaCl_2$ is confirmed by the formation of a white blur (which is nothing but a salt precipitate) in the sprayed area. If no precipitate is formed, it means that strength is lower than that identifiable with the reagent used.

The following reagents are used:

1. Ammonium oxalate in 3 percent aqueous solution. It gives a white precipitate on the pavement in the presence of a $CaCl_2$ solution between 5 and 30 percent in strength. In view of its high sensitiveness, it is used for determining the presence or the absence of $CaCl_2$ on the road.
2. Sodium sulfate in 5 percent aqueous solution. Positive reaction shows a concentration above 25 to 30 percent.
3. Sodium sulfate in 10 percent solution. Positive reaction identifies a strength above 15 to 20 percent.
4. Sodium sulfate in 25 percent aqueous solution. Positive reaction shows a concentration above 5 to 10 percent.

EXPERIMENT IN THE GARDENA VALLEY

In February 1970, the world skiing championships took place in 3 sport centers of the Gardena Valley. The area is directly accessible by railway. Main direct roads for access are Highway 12 (north-south) from the Brenner pass (Austria-Germany), Highway 49 of the Pusteria Valley (Cortina, San Candido, Austria), and Highway 48 of the Dolomites on the southern versant. Some traffic was expected from the Gardena and Sella passes in the eastern quadrant, but it was restricted by the avalanches and storms, resulting in difficulties for winter maintenance operations to keep these passes opened at all times.

The main drawback along Highway 12 was that which could result from a particularly hard winter. For the Bolzano-Brenner stretch, 1 turbine, 2 snowplows, and 2 spreaders were foreseen as being necessary.

After the tests made on the spot, it was decided that the area most directly requiring efficient operations was the highway of the Gardena Valley. There is no alternative route for traffic here; once traffic enters the road, it is compelled to follow it (Fig. 3).

Organization of Maintenance Operations

Maintenance operations, in which solutions of calcium chloride were used along Highway 242, started from Ponte Gardena, at an elevation of 469 m, and passed through the following localities: Ortisei, 1,234 m elevation and 13.3 km from the starting point; S. Cristina, 1,428 m elevation and 17.3 km from the starting point; Selva, 1,563 m elevation and 20.8 km from the starting point; and Bivio Miramonti, 1,800 m elevation and 26 km from the starting point. Here the roads to the Gardena pass, 2,121 m elevation, and to the Sella pass, 2,244 m elevation, branch.

The low section is between Ponte Gardena and Bivio Miramonti, 26 km, and has the following characteristics: Ponte Gardena to Ortisei—upgrade, medium mountain, and extraurban; Ortisei to Selva—false flat, almost urban, resorts, heavy pedestrian and vehicle traffic; and Selva to Bivio Miramonti—upgrade and high mountain, thinly populated.

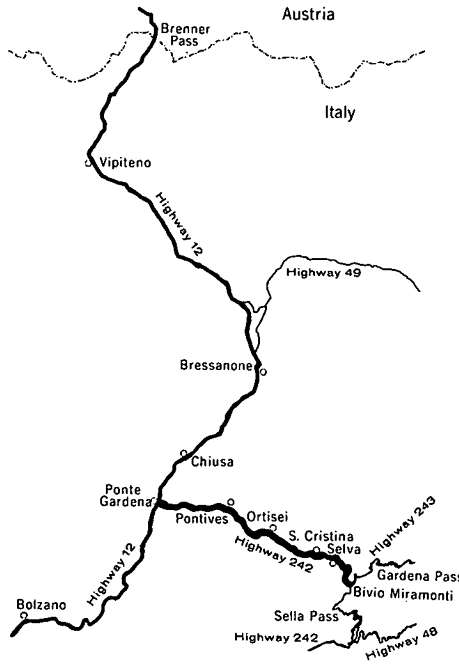

Figure 3. Location of experiment in Gardena Valley.

These different situations had some influence on the maintenance operations in that on the stretches from Ponte Gardena to Ortisei and from Selva to Bivio Miramonti the traffic is fluid, whereas on the intermediate stretch from Ortisei to Selva the typical characteristics of the winter resort centers prevail with frequent slowing down and some traffic jams. Under normal conditions, this has caused preventive treatments to be carried out during the evening hours when there is a usual pause in traffic and maintenance operations can proceed with a remarkable fluidity.

Equipment

Distributed along Highway 242 were four snowplow blades, two 5-m^3 tankers provided with attachment for a blade, and four rotating devices.

Equipment for Dissolving Chloride

Near the maintenance centers at Pontives and Santa Cristina, 2 containers with a mean capacity of about 12 m^3 were prepared. This permitted 2 loadings per tank per each container prepared. During the period of the championships, it was also decided to prepare the solutions by day, at variable moments, in the containers and to carry out the simultaneous loadings of the tankers alternately from one of the 2 containers. The solution in the empty container was replaced in the period of preventive treatments. At the end of the operation trip, the tankers stopped near the full container, were filled up again, and were placed on the prefixed spots, ready for a possible operation by night. When an operation by night was required, a ready supply container was available in addition to the 2 full tankers.

The 12-m^3 containers were equipped with a screen with a 2- to 3-mm mesh opening for the introduction of calcium chloride and with a pump to make solution recycling easier and to serve initially for water supply. Moreover, with the pump (centrifugal with diesel or electric motor) having a flow rate of about 1,500 liters/min, the tanker could be loaded rapidly.

Tankers

Two 6-m^3 tankers were mounted on a Fiat 639 car equipped with a rear sprinkling bar (sparger) with a flow rate adjustable by means of a centrifugal pump driven by an auxiliary motor. The sprinkling bar was 250 cm in length and 2 in. in diameter. The nozzles mounted on this sprinkling bar made it possible to obtain a flat, broad, and non-atomized jet; this last feature was fundamental.

All the control gears for opening, flow rate regulation, and opening only a part of the nozzles were in the cab. On the 2.50-m long sprinkling bar were mounted 3 pairs of opposed nozzles, K20 and K40, for sprinkling over about 4.50 m. In addition a pair of starting nozzles, P4060 and P40100, were mounted on the left end of the sprinkling bar for watering simultaneously, if need be, the remaining 3 to 3.5 m in the opposite direction of the road. The characteristics of the nozzles are as follows:

	Rate of Flow (liters/min) at Pressure					
Nozzle	0.5	1	2	3	4	Approximate Width Covered (m)
K20	6.5	9	13	16	18	1 to 3
K40	13	18	26	32	36	1 to 3
P4060	10	14	19	23	27	3 to 5
P40100	17	23	32	39	45	3 to 5

Amounts Used

The amounts used were of the standard strength adopted, i.e., 26 percent of calcium chloride (this concentration is obtained by dissolving 500 kg of calcium chloride in 1,000 liters of water). They were as follows:

Application	$CaCl_2$ Solid Flakes (g/m^2)	26 percent $CaCl_2$ Solution (g/m^2)	26 percent $CaCl_2$ Solution (cc/m^2)
Preventive	5	15	12.5
Maintenance	20	60	50

Preventive Treatments

Twelve to 25 cc of 26 percent solution correspond to 5 to 10 g/m^2 of flake $CaCl_2$. The amount necessary for treating the 27 km of Highway 242 in only one direction (about 4 m) is

$$5 \text{ g/m}^2 = 12.5 \text{ cc} \times 4 \text{ m} \times 27 \text{ km} = 1{,}350 \text{ liters}$$

The flow rates to be distributed by the nozzles were computed from the graph shown in Figure 4. As a function of the various amounts of $CaCl_2$ flakes per square meter and the speed of the tanker, the flow rates in liters/min necessary for the various requirements are plotted as ordinates. For example, at 5 g/m^2 and at a speed of 20 km/hr, a flow rate of 20 liters/min is required when treating a width of 4 m with 3 K20 nozzles opened at a pressure of 0.5 kg/cm^2.

For the various situations requiring preventive treatment, the following are values for sprinkling with 3 K20 nozzles over 4 m in amounts of 5 g/m^2:

Speed (km/hr)	Pressure	Flow Rate (liters/min)
10	0.2	10
20	0.5	20
30	1.0	30

Maintenance Treatments

Fifty cc of a 20 percent $CaCl_2$ solution correspond to 20 to 30 g/m^2 of flake $CaCl_2$. The amount necessary for treating the 27-km Highway 242 in only one direction (about 4 m) is

$$20 \text{ g/m}^2 + 50 \text{ cc} \times 4 \times 27 \text{ km} = 5{,}400 \text{ liters}$$

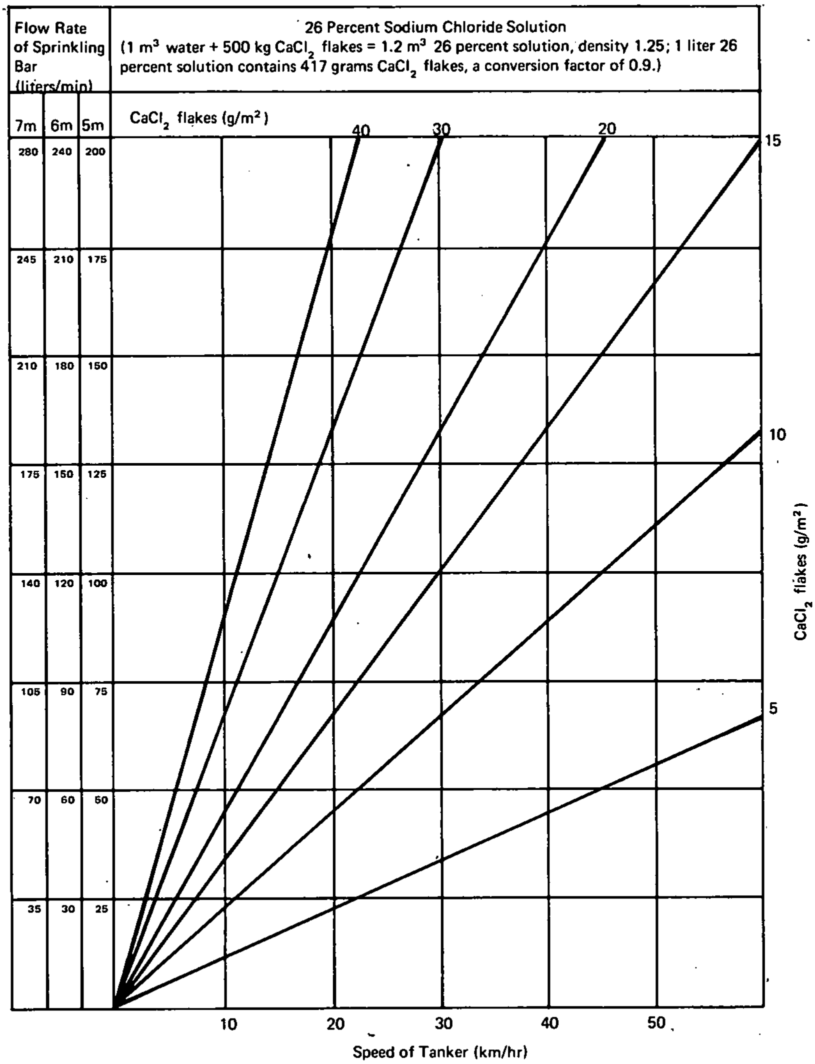

Figure 4. Flow rate of sprinkling bar in relation to speed of tanker and amount of flake $CaCl_2$, type 77-80.

The various flow rates and consequently the relative sprinkling pressure at the bar at the various speeds of the tanker with 3 K40 nozzles open and amounts of 20 g/m^2 are as follows:

Speed (km/hr)	Pressure	Flow Rate (liters/min)
10	0.5	35
20	1.5	70
30	4.0	105

The values with 3 K40 nozzles and 3 K20 nozzles open and 20 g/m^2 are as follows:

Speed (km/hr)	Pressure	Flow Rate (liters/min)
10	0.2	35
20	0.7	70
30	1.7	105

Figure 5. Sacks of $CaCl_2$ and tanker at Pontives.

Operations

From February 1 to 15 there were 7 snowfalls of different volumes. Although preventive treatment was carried out at a reduced amount of 5 g/m^2 $CaCl_2$, the 4 minor snowfalls on February 3-5, 11, 13, and 14 (4, 5, 4, and 8 cm respectively) were controlled without requiring the assistance of the snowplow blades. Only at the end of the snowfall was a control treatment carried out on the amount of 10 g/m^2 of $CaCl_2$ because of the humidity present on the pavement.

Similarly, the other 3 snowfalls on February 5-6, 10, and 14-15, all of 20 cm, were very well controlled, and, with the exception of the first one for which the snowplows started with some delay, the roadway was successfully cleared less than 2 hours after the end of the snowfall. Moreover, during snowfall (except for a few hours of the night from February 5 to 6) the surface of the roadway was not covered with hard snow. On the contrary it was always possible to maintain the snow in a wet and noncohesive state resulting in the use of very little de-icing chemical especially in view of the altitude and temperature.

The photographs in Figures 5 through 13 show the equipment used and the results obtained.

Operating Costs

The analysis of the costs is still in progress. However, the following figures can be given for the entire area (including the Sella and Gardena passes) from November 11, 1969, to February 15, 1970, the period between the first snowfall and the end of the world skiing championships:

Figure 6. Tanker at S. Cristina.

Figure 7. Tanker at Bivio Miramonti going to Gardena and Sella passes.

Figure 8. K40 and P40100 nozzles on sprinkling bar.

Figure 9. Snow after treatment with $CaCl_2$ solution.

Figure 10. Same snow after solution and traffic have eliminated its cohesion and adhesion to the pavement.

Figure 11. Road at Plan de Gralba after application of $CaCl_2$ solution.

Figure 12. Road at Selva after application of $CaCl_2$ solution.

Figure 13. Road at Bivio Miramonti after application of $CaCl_2$ solution.

Number of snowfalls	26
Aggregate depth, cm	165
Calcium chloride used (solid and liquid), tons	267
Number of applications with tankers	77
Average surface treated, m^2	210,000
Time of use of rotating devices, hours	2,100

CONCLUSIONS

The use of calcium chloride in aqueous solution represents a partial evolution of the traditional system of treatment with solid de-icing chemicals. The most significant aspect of this type of operation is that of the preventive treatments.

In addition to eliminating the scattering of the solid material by traffic, this type of treatment results in a higher total efficiency due to a better distribution and a closer contact with the pavement.

The Mont Blanc and the Gardena Valley experiments showed that the preventive treatments performed according to this system are by far more efficient than those carried out with solid de-icing chemical, even when the amount used is lower.

With a pavement "prepared" in this way (beyond the notion that "a salted road does not ice") it has been sufficient as a rule to plow during the snowfall and to apply calcium chloride solutions toward the end of the precipitation to obtain qualitatively high results. Because snow becomes progressively wet and noncohesive, it can be easily detached from the pavement. The final result of the treatments was to eliminate every snow trace and to have a bare pavement.

The solutions may be useful both in preventive and maintenance treatments during or immediately after the precipitation. It seems, however, advisable to specify that, apart from these 2 cases, this application is questionable and of transient effect. Using it to treat thick layers of pure ice or of packed or hardened snow either due to thermal alternations or to the traffic is a mistake, both technically and economically. Under these conditions, the use of solid materials is necessary. Therefore, the solutions should be used timely both in view of the winter season, in order not to operate on "heels" of hard packed snow, and with respect to the separate precipitations.

REFERENCE

1. Foglia, D., and Scotto, G. E. Economic Aspects, Equipment and Organisation of the Winter Maintenance of the Main Road in Italy. Turin, 1966.