Snow and Ice Control in California

Carl E. Forbes, Carl F. Stewart, and Don L. Spellman

This paper describes the present operations for snow removal and ice control in California where problems result from a variety of factors such as complex weather conditions, vast differences in elevation, wide temperature ranges, and changing traffic patterns. The paper includes a discussion of a research project initiated to study bridge deck heating and motorist and maintenance warning systems to minimize the hazards of frosting. Also discussed is a study to find a de-icing chemical for use as an alternative to the chloride salts. A comparative test was established to measure the rate as well as the quantity of ice that could be melted at various temperatures. Also considered was the effect of the chemicals on the friction factor of concrete; the corrosivity to steel, concrete, and other materials; the environment, including streams, domestic water supplies, fish, and plant and animal life; and maintenance personnel who will distribute the chemicals on the roadway.

California lies between the thirty-second and forty-second parallels of latitude. Elevations range from more than 200 ft below sea level in Death Valley to over 14,000 ft above sea level in the Sierra Nevada and Cascade mountain ranges. Approximately one-fifth of the state lies above the 5,000-ft elevation level.

This combination of range in latitude and range in elevation results in a multitude of different snow conditions. Although 5,000 ft is generally considered as the normal snow line, occasional heavy storms will fall as low as 500 to 1,000 ft above sea level. Although this is particularly true in the northern part of the state, it is not uncommon in the high desert region.

PRESENT OPERATIONS

Snow removal operations are performed on some 4,600 miles of the state highway system. Snowfalls range from a trace to over 750 in. annually at locations such as Donner Summit on Interstate 80.

Because of the extent and variation of the snow removal operations in California, it is almost impossible to concentrate equipment and extremely difficult to shift equipment from one location to another. Snow is removed from the Laguna Mountains east of San Diego and just north of the Mexican border all the way to the Oregon border. Storms in the southern part of the state will generally deposit snow in fairly concentrated areas and generally above the 5,000-ft level.

The mountain ranges lying to the north and east of the Los Angeles basin are heavily used for recreational purposes and have many miles of highway above 7,000 ft. Along the Sierra Nevada range toward the north, the snow line steadily decreases with the increase in latitude. On many occasions, heavy snowfall will occur in the entire northeastern corner of the state.

Temperatures during the winter have been measured well below -40 deg, and high winds frequently cause blizzard conditions on trans-Sierra routes and on US-395 just east of the summit of the Sierra Nevada mountain range. As a general rule, the snows on the west slope of the Sierra Nevada range are very wet while those on the east slope are extremely dry.

Guides to crews working in this operation define the level or quality of maintenance as expected in snow removal as follows:

Snow Removal

Snow should be removed from state highways as it falls, except on roads having extremely light winter traffic, which are closed after the first heavy snow.

Snow should be removed to the pavement surface for the full width of the traveled way. Widening to provide storage space for the next snowfall should immediately follow traveled way snow removal.

Areas within the right of way in front of stores, resorts, service stations and other roadside business establishments which serve the general public should be kept clear of snow when such areas have been graded and paved by the owner of the abutting property, so that heavy equipment can be operated.

Areas within the right of way adjacent to the traveled way which have been established to provide for public parking, such as locations where the public has access to snow sports, should be cleared. Snow should be removed from established public parking areas after the highway is cleared and equipment becomes available.

State forces will not remove snow from approaches leading from the traveled way to private property, but will operate so as to cause the least inconvenience to property owners. The windrow placed in front of approaches should be removed.

State forces are to assist local authorities in opening public road connections.

Chains shall be required when, in the judgment of the maintenance supervisor on duty, the road surface becomes unsafe for vehicular traffic due to snow and ice conditions.

Ice Control

Where ice, frost or snowpack causes slippery pavement, abrasives and/or chemicals should be applied. The treatment to be used shall be determined by the immediate supervisor in charge of maintenance of the particular section of highway. In areas subject to heavy snowfall, prolonged freezing temperatures and heavy traffic abrasives and/or chemicals should be spread on the pavement at the beginning of a snowstorm to prevent a snowpack from forming and to facilitate snow removal.

Patrol

On routes where freezing conditions are anticipated, special patrols should be scheduled on a continuous basis for the detection and correction of slippery conditions.

Bridges, Shaded Areas, and Other Known Isolated Locations of Acute Icing Conditions

Abrasives and/or chemicals should be applied at the beginning of a storm or whenever icing appears imminent.

Bridges which have a tendency to ice, especially when the approaches may be dry, should be given high priority attention both in patrolling and ice and frost prevention.

Under average winter conditions, sufficient plowing equipment is assigned to all snow stations to handle the amount of snow normally expected. Much of this equipment is geared to year-round use. This includes motor graders, dump trucks, and front-end loaders.

On lightly traveled roads at lower elevations, snow equipment generally consists of 2-ton or 4-ton dump trucks and a motor grader. With the addition of medium-sized reversible snow plows, the trucks used during summer weather are sufficient to remove the light snow or slush. During cold weather, a tailgate-type hydraulically operated chip spreader can be added for sanding and salting icy or frosty spots on the roadway. This combination can handle up to 10 or 15 miles of low elevation snowfall without much trouble providing the average daily traffic on the route is light.

On the main trans-Sierra artery, I-80, between San Francisco and Salt Lake City, we have constructed 3 major snow removal stations to house snow equipment and personnel to ensure that bare pavement will exist as often as is humanly possible during any 24-hour period. At these stations, both multipurpose and highly specialized snow removal equipment is assigned for winter work.

We now operate 73 rotary snowplows of various makes and ages. Our practice is to assign the newer rotaries to those areas having the trunk line through routes north to

Oregon and east to Nevada and the older rotaries to routes having low traffic density and winter closure points (by policy) somewhere short of the summits.

There are 528 displacement plows fitted to a variety of trucks of from 2- to 8-ton capacity. In addition, there are 140 four-wheel drive motor graders available for snowplow work. These graders are equipped with large hydraulic reversible push plows along with grader blades used for removal of packed snow and ice.

Various combinations of sand, cinders, and salt are used for icy pavement control depending on the location of the highway and bridge decks being treated. This material is spread with spinner-type chip spreaders, some of which are mounted under the tailgate of the dump trucks and some of which are bunker-type of 5-ton capacity permanently mounted for the winter onto the truck chassis. During 1968-69, 22,000 tons of rock salt was purchased for snowpack and ice removal throughout the state. Some 270,000 tons of abrasives such as sand or cinders were either purchased or made and then distributed and stored. Two districts, one in the northern end of the state and one on the eastern side of the Sierra Nevada Mountains, operate their own plants during summer months for producing screenings for winter use. Material is obtained from natural lava pits where the supply is practically unlimited and where the purchase of sand for this purpose is not economically practical.

Since the advent of raised pavement markers, the Department is currently experimenting with rubber snowplow blades for snow removal in the lower elevations. Raised markers are being used up to approximately the 2,500-ft level. From data that will be collected this winter, a better indication of the value of rubber blades will be obtained.

Snow removal in the higher elevations in southern California is also conducted on a 24-hour basis to ensure movement of the largest concentration of vehicles in the nation. With the exceptions of Cajon Pass Route (I-15) and Ridge Route (I-5), nearly all other routes subject to snowfall lead to or are in recreation areas.

Because of the snow sports available in the mountain areas of the south and the thousands of persons wishing to take advantage of the numerous, close-in winter recreation areas, one of the major problems is traffic control. In this respect, the California Highway Patrol works in close cooperation with the Division of Highways.

Facilities for the maintenance of all-year routes with bare pavements are necessarily large and complex. One example is the Kingvale Station constructed in 1961. It now consists of a 3-story dormitory that includes a large kitchen-dining room, recreation room, and individual bedrooms to house approximately 70 employees. Other facilities include a 32-bay truck shed with foreman's office, mechanics shop, and radio communications equipment room; a carport for private cars; a storage building; and a sandhouse with a separate gravity feed bunker for salt storage.

During summer months, the station is staffed with a foreman, an assistant, and 6 maintenance men. In the winter, limited-term personnel are recruited and supplemented by men from the valley crews as needed. The winter crew at this station consists of between 40 and 70 men depending on the intensity and duration of a storm. This station maintains 22 centerline miles of 4-lane divided freeway above the 6,500-ft elevation level. In addition to the routine maintenance equipment at this station, there are approximately 30 pieces of heavy snow removal equipment including 9 four-wheel drive motor graders, 6 modern rotary snowplows, and 8 trucks varying in size from 2 to 6 tons equipped with displacement plows.

One problem, which is increasing with the growth of recreational resort areas, is the necessity to dispose of snow by means other than those of plowing or blowing. Growth such as that found in the Lake Tahoe area and in the southern California resort areas requires that snow be hauled to designated disposal sites. Rotary plows equipped with directional chutes are used for loading. Trucks for hauling are the conventional 3-axle, 10-cu yd type. At the dump sites 1 or 2 tractor dozers are employed to stockpile snow and keep the disposal site in traversable condition.

Of the 9 trans-Sierra routes, 4 are closed with the first heavy snowfall of winter. Closures for the most part are in the 7,000-ft elevation range. Most of these routes are closed from November through May. At the end of winter, tractor dozers and rotary plows are used to remove the snow from the routes that have been closed during the snow season. Steady improvements in the capacity of snow removal equipment,

particularly rotary plows, have reduced the time to open these passes to an average of 3 weeks and the number of shifts a day from one to three.

Avalanche control is necessary on US-50 during winter months. Overhanging cornices build up several hundreds of feet above the highway, and artillery fire and explosive shells are used to trigger avalanches at preselected times when the road is temporarily closed. Two locations on this route have permanent platform gun mounts for a 75-mm recoilless rifle. The remaining 2 locations can be reached with a portable compressed-air gun. To date, we have been successful in preventing any serious accidental avalanche problem.

The Equipment Department works in close cooperation with field maintenance forces on the upgrading and improvement of all equipment used for maintenance of highways. As an example, when I-80 was completed over the Sierras, it was apparent that greater efficiency in the use of rotary snowplows would be necessary in order to keep the cost of snow removal work within reasonable limits and at the same time retain the high standard of traffic service to which the public had been accustomed. One of our older Snogos was rebuilt and equipped with a diesel engine for powering the augers and blower system. Later improvements to the cutter augers were made. A Rolba ribbon-type cutter was substituted for the original conventional 3-auger system. When measured in tons per hour of snow removed, the modified Snogo was 93 percent more efficient. Since this first unit was placed in operation, a total of 20 older Snogos have been rebuilt. To eliminate continued replacement of bottoms in bunker-type sand trucks, which rust through rapidly from salt, the Equipment Department is now furnishing stainless steel bunkers.

Specialized units that have proved to be labor saving in snow removal and ice control work are Hydro sanders, which replaced the old Missouri-type traction-driven sanders; air-operated snow post drivers with a magnetic holder built into the post leads; and B-type hydraulic reversible plows with a standardized frame and hoist assembly that is readily adaptable to several different truck sizes. This plow, working in 4 in. of snow, will displace approximately 2,290 tons of snow per hour when traveling at a speed of 25 mph. We are experimenting with a hydraulically operated vibratory grader moldboard mounted on a 4-wheel drive grader for use in removing ice pack from the pavement.

Most of the snow removal equipment is radio equipped. Base stations are maintained at each of the 85 highway superintendents' offices in the 11 district offices as well as at headquarters in Sacramento. Basically, operators of snow removal equipment can communicate directly with each other, with the foreman's mobile unit, and with the superintendent's office.

Road and weather information during winter months is reported on a daily basis. This information is accumulated in the territory superintendent's office and relayed to a district office. Here it is again accumulated and relayed via tape or teletype to the Sacramento headquarters. During all storms in winter months, headquarters communications operates on a 7-day, 24-hour basis. During these periods, information is disseminated to 14 broadcast stations hourly, which in turn transmit road conditions to the public. In addition, the Division maintains automatic telephone answering equipment located in several areas throughout the state. Information for this service is updated continuously.

In the 4 districts where most of the snow removal work occurs, foremen and superintendents' cars and pickups are equipped with a California Highway Patrol radio. The Patrol is also equipped with the Division's channel. The Division also maintains direct teletype communications with the states of Nevada, Oregon, and Washington for the exchange of road and weather reports.

VALLEY BRIDGE DECK ICING

In California's central valley area, where the temperature seldom falls below 20 F, flash frost or ice forms on bridge decks but not on the approach roadway. This spot icing is hazardous to motorists, and records show a sharp increase in accidents in the last few years due to this phenomenon.

The present motorist warning system of impending icing danger is a standard metal sign with the message SLIPPERY WHEN WET OR FROSTY. This is ineffective, primarily

because the sign is continuously visible to motorists, even in the summertime, and as such becomes an accustomed standard fixture along the roadway.

Because icing is intermittent and cannot be forecast, regular sanding patrols are not maintained. The icy bridge deck problem in the valley area is usually handled by one of the following procedures:

1. When there is a high potential for deck icing, a crew will stand by to apply a salt-sand mixture if necessary;
2. The Highway Patrol informs local maintenance personnel after ice has formed; and
3. An ice-preventive saline solution is periodically sprayed onto the decks. Each application is effective for approximately 3 days.

Adverse ramifications of these procedures are as follows:

1. Bridge deck salt-sanding is an additional task to valley maintenance personnel and results in extensive overtime work;
2. Bridge deck salt-sanding in a valley environment is usually done under the hazardous conditions of darkness, foggy weather, and high-speed traffic (the latter is usually more of a hazard to valley sanding crews than to mountain crews because of the valley motorist's unawareness of an icing problem);
3. When the Highway Patrol reports icing, it usually means the deck will have been iced for considerable time before maintenance personnel arrive to salt-sand;
4. The saline solution preventive method accelerates deck deterioration; and
5. Regardless of the application method, de-icing salts are causing deterioration in decks that have heretofore been maintenance-free.

Basically, the valley bridge deck icing problem falls into 2 areas: (a) safety to motorist and to maintenance crew, and (b) premature deterioration from de-icing chemicals.

Research

With an objective of alleviating these 2 problem areas, a research project was initiated in 1968 that consisted of (a) enclosing the underside of 6 T-girder spans to form simulated box-girder spans; (b) providing heat in three of them; (c) providing a motorist warning sign that is readable only when illuminated; and (d) installing telephone relay systems to local maintenance personnel. The sign and telephone relay systems are activated by ice detecting mechanisms.

Enclosures—Two spans of each of 3 structures were enclosed by attaching 1-in. thick urethane foam sheets to the bottom of the girders. Mastic between all joining sections made the enclosure airtight. Electrical resistance cables provided heat in 1 of the 2 spans so enclosed on each structure. The purpose of a nonheated span was to determine the effectiveness of dead air space under the deck in preventing frost from forming on its surface. Heat in the heated span was controlled by a thermostat and was on when the outside temperature was below 38 F. The amount of heat furnished could be manually controlled from 2½ to 10 W/sq ft of deck area. Thermocouples were placed in the surface and soffit of the deck in the enclosed spans and an adjacent nonaltered span, in the open space of the enclosed cells, and in the air alongside the bridge. Honeywell 20-point recorders continuously recorded the temperatures on a 5-minute cycle from midnight to 10:00 a.m. each day during the 3 months of potential frosting, December, January, and February.

Ice Detectors—Ice detectors manufactured by 3 different companies were installed: Nelson, Econolite, and Holley. Sensing transducers of the detectors were placed at the deck surface in the center of the inside traffic lane. The detectors were connected to the motorist warning sign and to maintenance telephone relay systems. The Honeywell recorders monitored the detectors.

Motorist Warning—An extinguishable message sign was installed on an approach 600 ft from one of the bridges. The 8-inch high letters of the message ICY BRIDGE are illuminated from behind by flashing flourescent tubes. When the tubes are not lit,

the letters blend in with the blank face of the sign, thus making the message indiscernible. Motorists' reaction to the sign was documented by a 2-man team, one at the sign and one at the bridge. They recorded any evidence of reaction such as brake lights coming on or sound of engine deceleration.

Maintenance Warning—Ice detecting mechanisms were connected through a telephone relay to a bell and flashing light in a highway patrol office in one area and in a continuously manned bridge tender's office in another. Local highway maintenance personnel were notified when a system was activated.

Results

For several reasons, such as shipment delays, priorities, high water, and failures, the entire installation was not completed until January 1970. Most of the system, however, was operating during the 1968-69 winter. Not too much was learned during this first winter, though, because it was very mild with respect to frosting or icing conditions. The air temperature dropped below 30 F only twice during the winter; the minimum was 26 F. Consequently, very little pertinent data are available from the 1968-69 winter. Data are being collected during the 1969-70 winter, but have not been analyzed in time to be included in this report.

There was a sufficient number of days during the 1968-69 winter with the minimum temperature in the low 30's, low enough for frosting to occur, to determine that the deck surface temperature over the enclosed but unheated spans followed very closely the deck surface temperature over the open span. In other words, the entrapped dead air space of the enclosed span had little effect on the deck surface temperature. There was about an 8 F temperature differential between the surfaces over the heated and open spans when 10 W/sq ft of deck area was applied to the heated cells.

During 3 occasions when heavy frost was forecast, the observation team observed motorists' reaction to the warning sign. On each occasion the temperature was low enough for frosting, and frost did form on the rails, but none formed on the deck. Because there was evidence of frost, the sign was turned on manually to observe motorists' reaction to it. On one occasion the reaction was very poor. Of 105 cars only 24 percent reacted; of 60 trucks, 23 percent reacted. On the other 2 occasions the reaction was better, but still not outstanding: reaction by 44 and 56 percent of automobiles and by 29 and 66 percent of trucks. Buses were included as trucks during the observations. Of 3 school buses that approached during one observation, only one driver made a discernible reaction: He applied his brakes after he was on the bridge.

The very mild winter prevented a thorough check of the ice detecting equipment. Based on this limited experience, however, the frost detectors are apparently not effective on bridge decks in the California valley area. The problem is in the moisture-detecting sensor. It appears that it is possible for enough moisture to be present to cause deck frosting, but not enough to act as a conductor between the electrodes of the moisture detector. Logically moisture would evaporate more rapidly from the heating element than it would from the deck at low temperature. When there is an abundance of moisture, this difference in evaporation rate would not be a problem; but it is when there is a minimum of moisture. Bridge deck frosting usually occurs with little moisture. Unsuccessful attempts were made to correct this problem by lowering the temperature of the heating element. More work along these lines was planned for the 1969-70 winter.

CONCLUSIONS

Based on the data collected thus far, the following conclusions seem warranted. These conclusions may be modified when all data are analyzed or when colder temperatures are experienced.

1. Dead air space under a deck, as occurs naturally in a box girder type structure, has little effect on deck surface temperature.
2. On the average, less than 50 percent of the motorists react adequately to an illuminated warning sign with the message ICY BRIDGE.

3. Conditions that lead to frosting on bridge decks in the California valley area appear to lie within ranges that are too sensitive for the ice detecting mechanisms currently available.

DE-ICING CHEMICALS

Because of the increasing use of chloride type de-icing salts, corrosion of bridge deck steel has resulted in a substantial amount of spalling of the concrete and subsequent repairs (1, 2, 3, 4, 5). As a result of the bridge deck reinforcing steel corrosion, some extensive studies have been made of de-icing chemicals other than chlorides (6, 7, 8, 9). Factors considered were (a) effectiveness and cost of melting ice, frost, and snow; (b) effectiveness and cost of preventing ice and frost; (c) corrosivity of the chemical to metals; and (d) effect of the chemical on the durability of construction materials, such as concrete and bituminous products.

A total of 17 different candidate chemical de-icing agents were subjected to various laboratory and field tests. Although all agents were not subjected to the same array of tests, those chemicals tested were as follows: sodium chloride, calcium chloride, sodium formate, tripotassium phosphate, tetra-potassium pyrophosphate, formamide, urea, sodium acetate, sodium benzoate, calcium formate, magnesium sulfate, trisodium phosphate, potassium oxide, sodium silicate, sodium sulfate, sodium pyrophosphate, and sodium hexametaphosphate.

Laboratory Ice-Melting Tests

The results of the laboratory ice-melting tests show that the melting rate of ice by various chemicals can be mathematically described. Also, the slope of the line in the regression analysis is apparently an "efficiency" term that can be used to compare various chemicals. However, the actual melting of ice is only applicable to a laboratory comparison and not necessarily representative of field performance.

Laboratory Ice Prevention Tests

Concrete slabs were cast and wet with solutions of various chemicals to determine the parameters of ice and frost prevention. The slabs were cooled to 0 F, placed in a room with 85 to 95 percent relative humidity, and observed for the formation of ice and frost. Other than sodium chloride, tetra-potassium pyrophosphate (TKPP) was one of the better ice prevention chemicals tested in this manner.

Field Skid Testing

Limited skid tests were performed by comparing solutions of sodium chloride and TKPP on an average-textured concrete pavement. A 60 percent concentration of TKPP temporarily reduced the friction factor of the concrete pavement. However, with a standard spread of sand being applied to the solution on the pavement surface, there was a significant recovery of skid resistance. Even without sand, the skid resistance, in all cases, recovered with time as a result of the evaporation and absorption of the water. A 30 percent solution of TKPP with and without the sand application has about the same effect on skid resistance as a 30 percent solution of sodium chloride.

Effect of the Chemicals on Air-Entrained Concrete

The effect of tap water and saturated solutions of sodium chloride and sodium formate on concrete was investigated. Sets of concrete cylinders containing 4½ and 7 sacks of cement per cubic yard were alternately immersed in each solution, then oven-dried at 140 F. Sodium formate caused rapid disintegration of the concrete. Visual observation and concrete length measurements indicate that sodium chloride slowly caused disintegration, while as expected, tap water had no measurable effect. Similar testing has been initiated using a saturated solution of TKPP, and thus far, the only conclusion that can be made is that TKPP does not attack concrete as rapidly as sodium formate.

Effects of the Chemicals on Steel

All de-icing chemicals tested that were dissolved in distilled water were corrosive to steel. Depending on the concentration, urea was more corrosive to steel than sodium chloride. To simulate concrete, we added lime to the corrosion test solutions. Sodium chloride was the most corrosive followed by urea and sodium formate. The least corrosive to steel was TKPP. However, the lime water containing all chemicals should be corrosive to zinc and aluminum because of the high pH. Because of the possibility of the nitrogen-type of de-icers penetrating into cracks that are usually filled with soil or sand, these chemicals may be converted into highly corrosive nitrates by bacterial action.

Ecology and Toxicity

Numerous chemicals were investigated for toxicity and their possible effect on the ecology. From a toxicity standpoint, TKPP should be handled in the same manner as sodium and calcium chloride. From an ecology standpoint, nitrogen compounds, or those chemicals that can degrade into nitrogen compounds, are the ones most likely to "burn" plants and stimulate algae growth in adjacent streams. In addition, the nitrogen compounds, as nitrates in ground waters, are being currently studied by others for their toxic effects on infants (14). Phosphate compounds appear to be less potentially active in their effect on the environment than are nitrogen compounds.

Laboratory Ice-Melting Tests

In California, de-icing chemicals are used in the following ways: (a) They are spread on the pavement or bridge deck to prevent the formation of ice and frost; (b) at the beginning of a snow storm, they are spread on the surface to partially melt the snow and also to break the adhesion of the snow to the pavement surface; and (c) during and after a snow storm, the crystalline chemicals are spread on the surface to melt and break up the structural properties of the compacted snow.

Two methods for the application of the chemicals have been used: (a) The salt is dissolved in water and the solution is sprayed on the pavement to prevent the formation of ice and frost; and (b) salt crystals both with and without sand or cinders have been used for frost and ice prevention as well as for the removal of compacted snow.

These laboratory tests did not duplicate field conditions with regard to the effect of traffic, which is significant, and the actual process of formation of ice and frost as related to relative humidity and other changing weather factors. The general method used in testing for ice-melting capabilities was previously reported (9) except that larger quantities of distilled water were used. Also the melted ice at the prescribed test temperatures was measured at melting time intervals of 5, 10, 15, 30, 60, and 120 minutes, and also at 24 hours.

The ice-melting test data were first graphically plotted, and it was observed that the quantity of ice melted was related to the base 10 logarithm of the test time. By the method of least squares, a regression analysis was made of all ice-melting data. The resulting equations are given in Table 1. Care should be exercised when computing the depth of ice melted at time intervals of less than 5 minutes or greater than 24 hours. For time intervals of 5 minutes or less, the measurements were relatively inaccurate because the amount of melted ice was usually very small. The measurements generally did not extend beyond a 24-hour period.

As the data given in Table 1 show, the de-icing chemicals can melt a considerable depth of ice, given sufficient time. These laboratory results show sodium chloride at the laboratory test temperature to be greatly superior to calcium chloride. What this test does not demonstrate is the ability of a large crystal to "bore" through the ice and thus break up its structural properties so that chain action can accelerate its transformation into "slush." The slush can readily be plowed or otherwise removed from the pavement.

As indicated by the results of the regression analysis, the most apparent indication of ice-melting efficiency is the first constant in the equation, that is, the multiplier of

TABLE 1

DEPTH OF ICE MELTING BY DRY POWDERS

Temperature (deg F)	Chemical	n	Equation	Coefficient of Correlation	Standard Error of Estimate (in.)
10	Sodium chloride	4	$Y = 0.297 \log_{10}X + 0.234$	0.996	0.010
	Calcium chloride	4	$Y = 0.124 \log_{10}X + 0.221$	0.937	0.018
	Sodium formate	3	$Y = 0.270 \log_{10}X + 0.216$	0.977	0.023
	TKPP	5	$Y = 0.039 \log_{10}X + 0.069$	0.949	0.006
17	Sodium chloride	12	$Y = 0.185 \log_{10}X + 0.245$	0.925	0.049
	Calcium chloride	5	$Y = 0.161 \log_{10}X + 0.239$	0.992	0.009
	Sodium formate	12	$Y = 0.145 \log_{10}X + 0.206$	0.911	0.042
	TKPP	6	$Y = 0.062 \log_{10}X + 0.090$	0.953	0.010
	Urea	11	$Y = 0.074 \log_{10}X + 0.113$	0.854	0.026
24	Sodium chloride	12	$Y = 0.444 \log_{10}X + 0.467$	0.992	0.040
	Calcium chloride	12	$Y = 0.250 \log_{10}X + 0.347$	0.995	0.018
	Sodium formate	12	$Y = 0.412 \log_{10}X + 0.434$	0.997	0.023
	TKPP	12	$Y = 0.096 \log_{10}X + 0.145$	0.961	0.019
	Tripotassium phosphate	5	$Y = 0.147 \log_{10}X + 0.179$	0.993	0.008
	Sodium acetate	5	$Y = 0.146 \log_{10}X + 0.179$	0.988	0.001
	Urea	7	$Y = 0.212 \log_{10}X + 0.227$	0.993	0.014
	Sodium benzoate	4	$Y = 0.214 \log_{10}X + 0.199$	0.973	0.021

Note: Y = depth of ice melted, in., and X = time, hr. Chemical was spread at 0.25 lb/sq ft.

the time variable. In effect, this constant is the "slope" of the line, and also a mathematical definition of the rate of melting. The greater the numerical value of this constant is, the faster the ice melts. The "efficiency" of melting rate constants as given in Table 1 will also vary with the physical size of the grains of the chemical. It is believed that a grain of high bulk will continually be in physical contact with the ice interface, and the melting rate will be more rapid because of the high concentration of the chemical at this point. As a result, the ice-melting constants may be used not only to compare chemicals but also to evaluate the relative efficiency of various grain sizes for a particular chemical. The relative use of grain size of the chemical could be related to its use; for example, within limits, a small grain size may be more appropriately used for direct application to thin ice on the pavement surface. Conversely, a large grain could be used during the snow removal operation because it would bore through the thicker layer of snow more rapidly. In other cases, a mixture of fine and coarse grains may produce the best results.

Laboratory Ice Prevention Tests

In order to determine if the alternative chemicals could prevent the formation of ice, 34 concrete slabs were cast, each having a surface area of approximately 130 sq in. and depth of 2½ in. These slabs were made from a typical 6-sack concrete mix design by using a local stock aggregate and 4.7 percent entrained air. Concrete was consolidated by means of vibration, and the surfaces of the slabs were given a surface texture similar to a typical in-service bridge deck. The tests were accelerated by moist curing the slabs for a minimum of 16 hours and then steam curing them for 17 hours prior to the application at the test solutions.

All slabs were identified and areas outlined on each slab surface for tests with the British Portable Friction Tester. Friction tests were performed initially on each slab by the conventional test method using water. After solutions were applied, these friction tests were performed on slabs that had been frozen and then allowed to warm to a temperature of about 45 F. The purpose of these tests was to determine what lasting effects, if any, the solution might have on skid resistance. The numerical results are not considered conclusive as there was difficulty in duplicating the measurements.

Six slabs were tested in each test set. In each set, one slab remained untreated as a reference or control slab. The concrete slabs were placed in the cold room for at least 16 hours before solutions were applied. Temperatures in the cold room varied from -10 to 0 F during the tests. De-icing chemical solutions were applied in the cold room by brushing them onto the slab surfaces. The slabs remained in the cold room for a minimum of 30 minutes after the solutions were applied. Before the slabs were removed, the visual condition of the surfaces was recorded and a temperature reading

was taken on the control slab. The slabs were then moved to a humidity-controlled room where observations were made and recorded at short time intervals. After all slabs had thawed and the surface temperatures had reached approximately 45 F, the slabs were retested with the British Portable Friction Tester.

Three amounts of chemicals—0.5, 1.0, and 1.5 oz/sq ft—were applied on each set of slabs during subsequent tests. Results of tests indicated that the rate of application was critical for some chemicals, but not for others (Table 2). Most satisfactory at any rate of application were the TKPP solutions. They have relatively high specific gravities and are not quickly absorbed into the concrete or dried out through evaporation. Friction tests conducted in the lab did show some loss of skid resistance for the TKPP

TABLE 2

DE-ICING ABILITY OF CHEMICAL SOLUTIONS ON CONCRETE SLABS

Solution (oz/sq ft)	De-Icing Chemical	Percent Solution (by weight)	Temp (deg F)[a]		Application Rate (lb/sq ft)	British Portable Friction Readings[b]	
			Frost	Ice		Initial	After First Cycle
0.5	TKPP	60	+20	None	0.034		
	TKPP	30	+29	None	0.014	73	63
	TKPP + formamide	50-10	None	None	0.032		
	TKPP + formamide	25-5	+24	None	0.013	72	72
	Urea	20	+32	+32	0.007		
	Urea	40	+24	+20	0.015		
	Sodium chloride	10	+32	+28	0.004		
	Sodium chloride	25	+32	None	0.010		
	Form-urea-H_2O	75-20-5	+32	None	0.029		
	Form-urea-H_2O	50-40-10	+32	+15	0.019		
	Sodium benzoate	25	+32	+20	0.009		
	Sodium benzoate	37	+24	+10	0.014		
	Urea + calcium formate	17-8	+32	+28	0.008	70	70
	Calcium chloride	30	+30	None	0.013	69	71
	Magnesium sulfate	20	+31	+29	0.008	70	71
	Sodium formate	25	+32	None	0.010	66	60
	Plain slab	0	+32	None	0	62	60
1.0	TKPP	60	None	None	0.068	61	55
	TKPP	30	+29	None	0.028	70	53
	TKPP + formamide	50-10	None	None	0.063	67	61
	TKPP + formamide	25-5	+25	None	0.026	72	61
	Urea	20	+32	+30	0.014	72	73
	Urea	40	+28	+22	0.030	72	74
	Sodium chloride	10	+32	+22	0.008	69	70
	Sodium chloride	25	None	None	0.020	75	72
	Form-urea-H_2O	75-20-5	+31	None	0.058	52	54
	Form-urea-H_2O	50-40-10	+30	+5	0.040	65	62
	Sodium benzoate	25	+19	+6	0.018	72	68
	Sodium benzoate	37	+12	+4	0.028	68	65
	Urea + calcium formate	17-8	+32	+26	0.016	70	66
	Calcium chloride	30	+29	None	0.026	69	60
	Magnesium sulfate	20	+30	+24	0.016	70	61
	Sodium formate	25	+32	None	0.020	68	63
	Plain slab	0	+32	None	0	62	62
1.5	TKPP	60	None	None	0.102	61	50
	TKPP	30	+30	None	0.042	73	49
	TKPP + formamide	50-10	None	None	0.096	67	49
	TKPP + formamide	25-5	None	None	0.039	72	57
	Urea	20	+32	+20	0.021	72	73
	Urea	40	+30	+18	0.045	72	71
	Sodium chloride	10	+32	+17	0.012	69	75
	Sodium chloride	25	None	None	0.030	75	77
	Form-urea-H_2O	75-20-5	None	None	0.087	52	49
	Form-urea-H_2O	50-40-10	0	None	0.057	65	63
	Sodium benzoate	25	+20	0	0.027	72	68
	Sodium benzoate	37	+12	0	0.042	68	56
	Urea + calcium formate	17-8	+32	+12	0.024	70	66
	Calcium chloride	30	None	None	0.039	69	58
	Magnesium sulfate	20	+32	+15	0.024	70	56
	Sodium formate	25	+25	None	0.030	62	59
	Plain slab	0	+32	None	0	62	60

[a]Temperatures on the surface of the untreated slabs, above which no frost or ice formed on the chemically treated slab, for the first cycle.
[b]Each reading is the average of 3 test readings; slabs were all initially cooled to 0 F.

solutions; however, the test results for reasons previously mentioned were not considered conclusive. The main disadvantage of the British Portable Friction tests is the small area tested and poor reproducibility. For this reason, field tests were carried out using an ASTM-type towed trailer skid tester.

Field Skid Tests

Tetra-potassium pyrophosphate was found to be one of the more effective chemicals tested for the purpose of preventing ice formation on concrete. Thus, it was decided to implement a field testing program to determine its effect on the skid resistance of pavement.

Sections of approximately 200-ft lengths of concrete pavement were marked off for each test using the towed trailer skid tester. Each section of pavement was tested initially at a 40-mph speed by the conventional procedure, using water. Solutions of sodium chloride and tetra-potassium pyrophosphate were then sprayed at various rates of application and the sections retested for skid resistance. Both 30 percent TKPP and 60 percent TKPP solutions were used in addition to a 25 percent sodium chloride solution. Additional tests were run on sections with sand applied over the solutions. Three rates of application of solutions ranging from light to heavy were tested. The results of these skid tests are given in Table 3.

These tests were conducted on a concrete pavement surface that could be classified as fairly smooth and typical of the surfaces to be found on many bridge decks throughout the state. The average skid number of all test sections on which plain water was used was 46.8 for a trailer speed of 40 mph.

From the limited number of tests performed on this particular pavement surface, the following observations are noted:

1. Solutions of 60 percent TKPP at all application rates caused significant loss in skid resistance when no sand was applied to the pavement. It would not be recommended that this amount of solution be applied without sand. Only an application rate of less than 0.02 lb/sq ft at this 60 percent concentration might be suggested and this should be followed by a standard spread of sand. A standard spread of sand refers to the normal application rate now used by maintenance personnel.

TABLE 3

SKID TEST RESULTS

Concrete Pavement Section	De-Icing Chemical	Percent Solution (by weight)	Application Rate (lb/sq ft)	Sand Applied	Skid Number				
					With Water	With Solution			
						Immediately	After 0.5 Hr	After 1.0 Hr	After 1.5 Hr
1	TKPP	60	0.032	No	48.2	29.0	–	–	–
2	TKPP	60	0.022	No	46.3	30.9			33.8
3	TKPP	60	0.039	Yes, standard	46.3	38.6			39.0
4	TKPP	60	0.070	Yes, standard	45.8	35.7			37.6
5	TKPP	60	0.014	Yes, light	47.2	46.3			30.6
1	TKPP	30	0.012	No	48.2	44.3			70.7
2	TKPP	30	0.018	No	46.3	44.3			64.6
3	TKPP	30	0.034	No	46.3	44.3			48.7
4	TKPP	30	0.014	Yes, standard	45.8	48.2		55.0	
5	TKPP	30	0.018	Yes, standard	47.2	46.3		53.1	
6	TKPP	30	0.036	Yes, standard	50.1	46.3		47.2	
7	TKPP	30	0.057	Yes, heavy[a]	43.4	41.4	41.0		
9	TKPP	30	0.062	Yes, heavy[b]	47.7	40.5	43.4		
1	NaCl	25	0.010	No	48.2	57.0			67.2
2	NaCl	25	0.017	No	46.3	43.8			59.1
3	NaCl	25	0.025	No	46.3	44.3			46.3
4	NaCl	25	0.009	Yes, standard	45.8	48.2		54.5	
5	NaCl	25	0.017	Yes, standard	47.2	42.9		48.7	
6	NaCl	25	0.020	Yes, standard	50.1	40.5		41.9	
7	NaCl	25	0.036	Yes, standard	53.4	42.9	42.9		
9	NaCl	25	0.042	Yes, standard[b]	47.7	43.4	47.2		

[a]After solution was applied.

[b]Before solution was applied.

2. Solutions of 30 percent TKPP showed much more promising results. Without sand, only small decreases in skid resistance occurred. A standard application of sand broadcast over the solutions increased skid resistance. Use of a 30 percent solution concentration is proposed, the rate of application dependent on existing concrete and climatic conditions. A standard spread of sand should be applied in conjunction with the solution.

3. Solutions of 25 percent sodium chloride (saturated concentration) were tested for comparative results. Skid numbers quite similar to the 30 percent TKPP solutions were obtained on tests run immediately following application of the chemicals.

A significant observation was made during these field tests. All TKPP solutions remained longer on the pavement surface than did sodium chloride solutions. Sodium chloride solutions were more readily absorbed into the concrete or lost because of evaporation. This ability of TKPP solutions to remain longer on the surface may be an important feature in that the de-icing ability is probably extended over a longer period of time.

After test sections sprayed with the TKPP solutions had eventually dried, the pavement was covered with a white deposit, suggesting that perhaps the de-icing ability of the solution would be restored if the surface were rewet with water, frost, snow, or ice.

Laboratory Concrete Tests

To determine if the chemicals could adversely affect concrete, we subjected 84 cylinders ($4\frac{1}{2}$ by 9-in.) with gage plugs at each end to various tests. The cylinders were made from 2 mix designs: (a) $4\frac{1}{2}$ sacks of cement per cubic yard at $2\frac{3}{4}$-in. slump and 5.8 percent entrained air, and (b) 7 sacks of cement per cubic yard at 4-in. slump with 4.5 percent entrained air. All cylinders were cured for a minimum of 28 days by complete immersion in tap water at room temperature, then oven-dried at 140 F for 28 days in a forced-draft oven. One test alternately immersed 42 of the cylinders in a saturated solution of the chemical for 7 days, and then subjected them to oven-drying at 140 F for 7 days. Changes in length were measured after each cycle by means of a comparator. The results of the length change measurements after 8 cycles of alternate immersion testing are shown in Figures 1 through 6. Weight measurements were made at similar times along with periodic observations and photographs. The other 42 specimens were partially immersed to a depth of 2 in. in the various solutions.

The following is a summary of the results:

1. Both $4\frac{1}{2}$- and 7-sack concrete cylinders are not significantly affected after 7 cycles of wet-dry tests in tap water.

2. Sodium formate caused severe deterioration of both $4\frac{1}{2}$- and 7-sack concrete specimens. Visible surface scaling was evident after only 2 cycles. Figure 7 shows the condition of $4\frac{1}{2}$-sack concrete specimens after removing them from solutions at the completion of the wet portion of the fourth cycle. Crystal growth and severe disintegration are obvious. Only one more cycle was possible before terminating tests employing sodium formate because of the extreme disintegration of the concrete.

3. Concrete cylinders cycled in a saturated sodium chloride solution were first observed to have scaling of the surfaces of all cylinders after the third cycle. This scaling did not become severe through 7 cycles and is believed to be primarily confined to the surface area and not of major concern yet to the structural strength of the concrete. The distress observed is similar to that occurring in normal air-entrained concrete exposed to similar salt concentrations.

4. Thus far, observations of the test with the saturated solution of tetra-potassium pyrosphosphate have not revealed any noticeable detrimental effect on concrete after 3 cycles; however, not enough data are available at this time to make any conclusions on the long-term effect of the chemical.

Figures 7, 8, and 9 show the appearance of $4\frac{1}{2}$-sack concrete after 4 cycles of alternate immersion and oven-drying. Figures 10 and 11 show the amount of concrete disintegration after 5 and 6 cycles of alternate immersion in sodium formate for the $4\frac{1}{2}$- and 7-sack concrete.

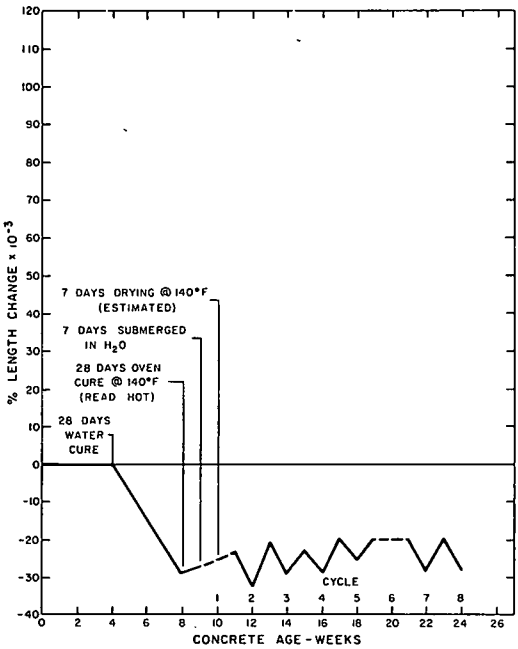

Figure 1. Alternate immersion tests of 4½-sack concrete in tap water.

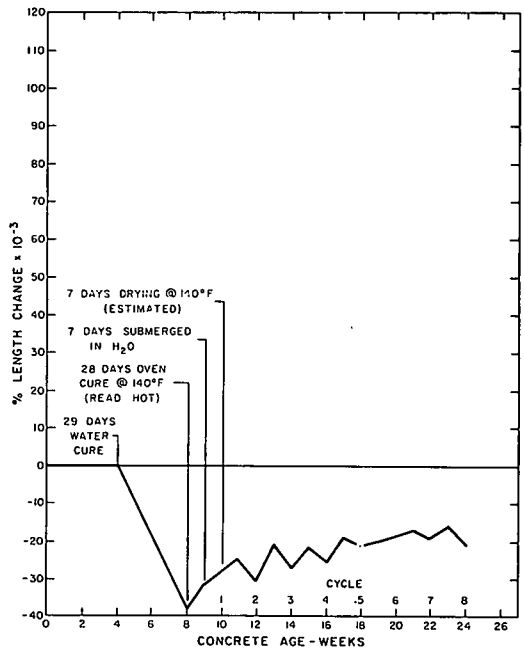

Figure 2. Alternate immersion tests of 7-sack concrete in tap water.

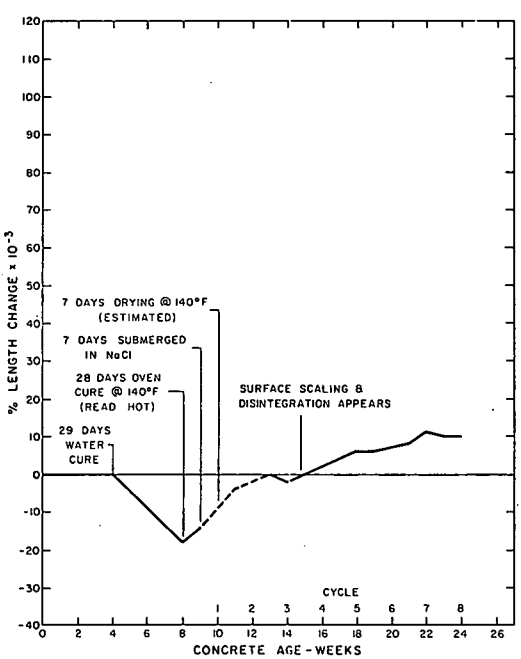

Figure 3. Alternate immersion tests of 4½-sack concrete in sodium chloride solution.

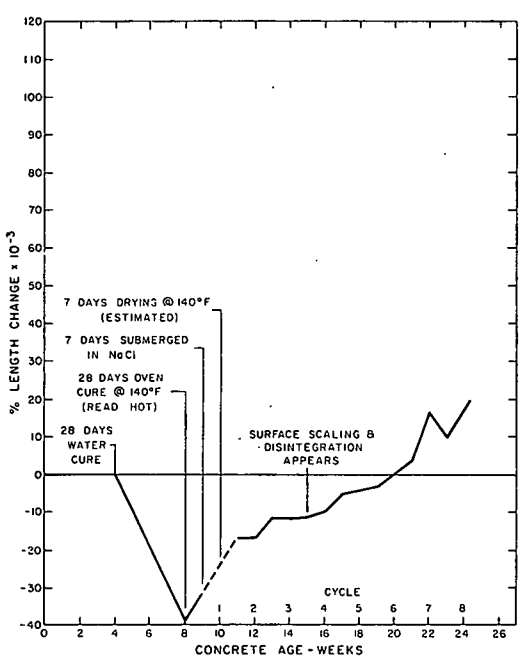

Figure 4. Alternate immersion tests of 7-sack concrete in sodium chloride solution.

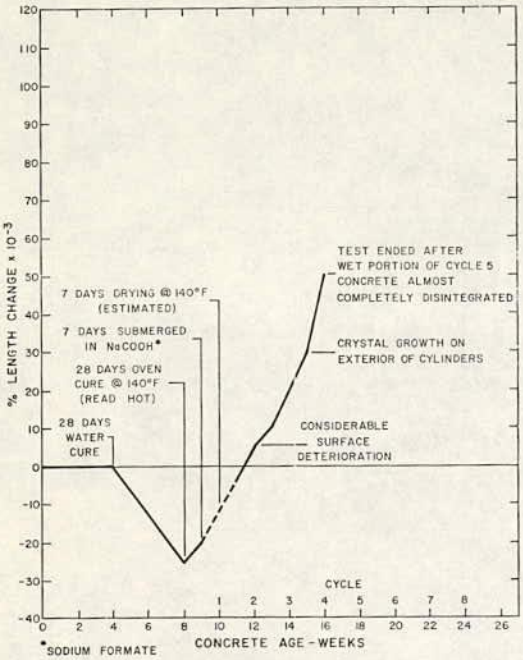

Figure 5. Alternate immersion tests of 4½-sack concrete in sodium formate solution.

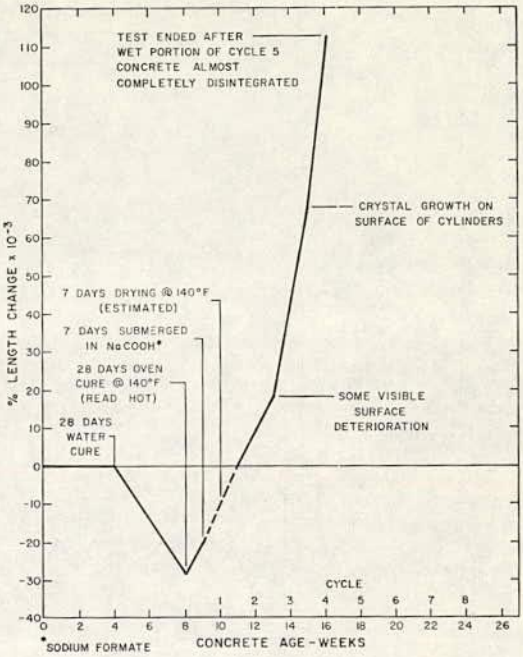

Figure 6. Alternate immersion tests of 7-sack concrete in sodium formate solution.

Corrosion Tests

One of the most important properties of any de-icing chemical considered as a substitute for sodium chloride is that it be noncorrosive to reinforcing steel in bridge decks, or at least only slightly corrosive. A simple corrosion screening test was chosen to evaluate the corrosivity of the various concentrations of chemical solutions. The method used was to immerse mild steel corrosion probes in the solutions and measure the corrosion rate of the steel by means of the change in the electrical resistance of a thin metal strip. The resistance change is caused by any loss in metal cross section as corrosion proceeds. The equipment used is shown in Figure 12.

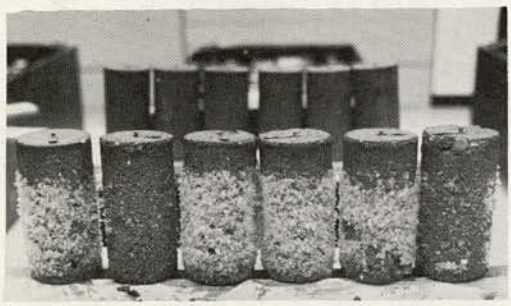

Figure 7. Condition of 4½-sack concrete after 4 cycles of alternate immersion in sodium formate and oven-drying.

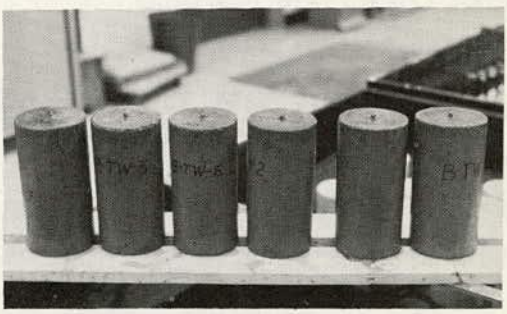

Figure 8. Condition of 4½-sack concrete after 4 cycles of alternate immersion in tap water and oven-drying.

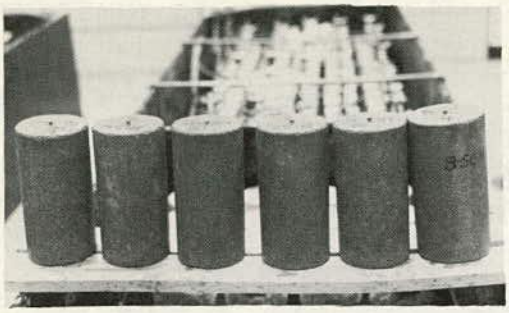

Figure 9. Condition of 4½-sack concrete after 4 cycles of alternate immersion in sodium chloride and oven-drying.

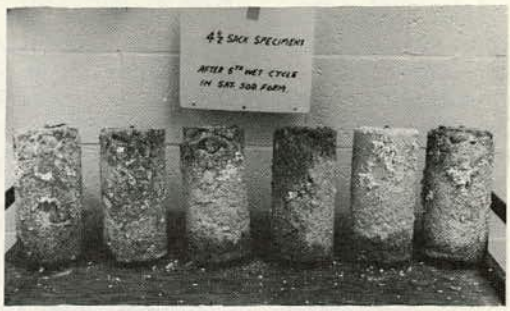

Figure 10. Condition of 4½-sack concrete after 5 and 6 cycles of alternate immersion in sodium formate.

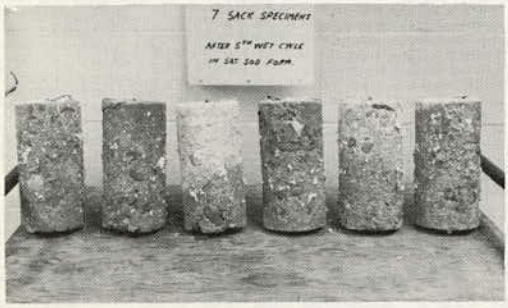

Figure 11. Condition of 7-sack concrete after 5 and 6 cycles of alternate immersion in sodium formate.

Figure 12. Corrosimeter testing apparatus.

Upon completion of each corrosion test, the pH of each solution was determined. Some of the results of corrosion and pH tests are given in Table 4. The corrosion tests were run on each chemical when dissolved in distilled water and also in lime-saturated distilled water. Tests using lime-saturated water are believed to simulate conditions found in concrete where the pH of salt-free concrete is about 12 or 13. The corrosion test probes were normally submerged in each test solution for 3 days. Corrosion rate for the probe immersed in distilled water was 7.2 mils per year. For the probe immersed in the lime or calcium hydroxide solutions, the rate was 0.6 mils per year.

TABLE 4

CORROSION TEST RESULTS

Percent Solution (by weight)	Solutions in Distilled Water								Solutions in Lime-Saturated Distilled Water							
	Sodium Chloride		Urea		Sodium Formate		TKPP		Sodium Chloride		Urea		Sodium Formate		TKPP	
	Mils	pH	Mils	pH	Mils	pH	Mils	pH	Mils	pH	Mils	pH	Mils	pH	Mils	pH
1	1.6	7.2	6.6	7.2	2.0	8.4	0.5	9.5	1.5	11.6	3.8	12.0	3.1	11.7	0.3	12.3
2	1.5	7.1	1.9	7.2	2.9	7.2	1.2	9.5	4.5	11.4	0.6	12.4	0.6	11.6	0.4	12.6
4	1.6	7.0	2.6	7.6	1.8	7.4	1.3	9.4	3.6	11.2	0.0	12.5	0.5	11.3	1.0	12.3
8	1.1	6.9	6.5	7.6	1.4	7.5	3.7	9.4	2.6	10.9	0.2	12.2	0.7	11.2	0.7	12.1
16	2.1	6.9	5.4	7.8	1.0	7.6	4.0	9.3	2.6	10.9	1.4	12.3	0.3	11.2	0.5	12.3
30	1.0	7.0	3.9	8.0	0.0	7.6	0.8	9.5	0.0	10.2	—[a]	12.3	0.0	10.8	0.4	11.8

[a]Reading not obtained because of damaged probe.

Note: Mils is corrosion rate in mils per year and pH is hydrogen-ion concentration after test.

Some important observations from these corrosion tests are (a) no completely noncorrosive de-icing chemical has been tested; (b) tetra-potassium pyrophosphate produced the most promising results when tested in lime-saturated water solution insofar as a minimum corrosion rate was observed; (c) sodium chloride solutions in lime-saturated distilled water gave higher corrosion rates than corresponding solutions in plain distilled water (this occurred at 2, 4, 8, and 16 percent solutions); and (d) urea and sodium formate solutions in lime water at 1 percent concentrations were found to be fairly corrosive but almost noncorrosive at all higher concentrations.

Ecology and Toxicity

Recently there has been quite an increase of interest in the effect of de-icing salts on plant life (10, 11, 12). As a result, this investigation of alternative de-icing chemicals also included emphasis on the effect of these new materials on the ecology. Several agencies and individuals were asked to comment on various chemicals. Only a few of the many comments received will be discussed in this report.

Toxicity—In a private communication, a representative of the California State Environmental Health and Consumer Protection Program has related that the same precautions should be used when handling tetra-potassium pyrophosphate as is used for sodium and calcium chloride. Urea should not have any adverse effect on humans.

Ecology—In a private communication of September 3, 1969, with the College of Agriculture, University of California, Davis, a professor stated that in the East sodium and calcium chloride have resulted in soil conditions that are toxic to most plants. Urea should not cause any toxicity to plants unless used in large quantities, although it might stimulate an undesirable growth along the highway. Tetra-potassium pyrophosphate should give the least trouble from a residue standpoint because it should be tied up by the soil and be unavailable for plants.

In a private communication of November 4, 1969, from the regional forester's office of the Forest Service, U.S. Department of Agriculture, an opinion was offered that urea could leach into streams and lakes and cause an increase in algae or other aquatic plant growth. It was also stated that urea or tetra-potassium pyrophosphate would not be as damaging to the roadside environment as the calcium and sodium chlorides.

In a written communication of July 28, 1969, from the Soil Conservation Service, U.S. Department of Agriculture, an opinion was given that extremely high concentrations of urea would kill all plants next to the roadway, but the greatest hazard is to streams and lakes wherein it could greatly increase plant growth and add to pollution. The opinion was also given that tetra-potassium pyrophosphate would be the least hazardous to plants, and it adds little to the pollution problem because it would be applied to normally acid soils where snow and ice occur and would thus be fixed by the soil.

Consideration should also be given to the influence of nitrogen compounds on the nitrate buildup in ground water. Currently, the California State Department of Public Health is studying the toxic effects on infants under 6 months of age of nitrates in drinking water from wells (14).

Discussion of Research

The studies of alternative de-icing salts are not complete. Many chemicals that have been tested in one phase of the program have not been tested in other phases. The reason is that it is most urgent to find a relatively noncorrosive salt at a reasonable cost at the earliest date.

During the investigation, sodium formate had an ice-melting capability that was nearly equal to the chlorides. However, it was found in the alternate immersion tests that concrete would be rapidly attacked. Rather than continuing the testing of this chemical, which would necessarily include finding means of offsetting its aggressiveness to concrete, we diverted attention to other chemicals that did not exhibit this characteristic. We intended to retrace and continue some of the research steps with some of the less costly de-icing chemicals if the alternative chemicals do not fit all requirements. However, this would probably mean testing many combinations of chemicals and that type of investigation does not usually give rapid results.

Urea and tetra-potassium pyrophosphate appear to be among the better candidates tested as alternative de-icing chemicals. However, they may need to be modified to reduce corrosivity to steel. We believe that the phosphate may be mixed with lime and thus be rendered relatively noncorrosive to steel. However, we anticipate that the lime-phosphate mixture will still be somewhat corrosive to zinc and aluminum.

Our tests show that urea in water is corrosive to steel and, at certain concentrations, it appears to be more corrosive than salt (13). The combination of urea, lime, and water significantly reduces the corrosive action to steel. However, there is some concern about the corrosive properties of urea on bridge decks that have cracked concrete and its possible effect on plant life. Urea is a nitrogen compound, and, coupled with the soil in the cracks, it could possibly be reduced by bacterial action to highly corrosive nitrates. Also, urea and other nitrogen compounds could offer the greatest hazard in stimulating algae growth in adjacent streams. Because of possible effects on the environment, controls may be necessary to govern the use of fertilizer types of materials in certain geographic areas.

ACKNOWLEDGMENT

The work on de-icing chemicals was performed in cooperation with the Bureau of Public Roads, Federal Highway Administration, U.S. Department of Transportation. The work was performed under the direction of R. F. Stratfull who was also helpful in the preparation of this report. The opinions, findings, and conclusions expressed are those of the authors and not necessarily those of the Bureau of Public Roads.

REFERENCES

1. Evaluation of Methods of Replacement of Deteriorated Concrete in Structures. NCHRP Rept. 1, 1963.
2. Boies, D. B., and Bortz, S. Economical and Effective Deicing Agents for Use on Highway Structures. NCHRP Rept. 19, 1965.
3. Tripler, A. B., White, E. L., Hayne, F. H., and Boyd, W. K. Methods for Reducing Corrosion of Reinforcing Steel. NCHRP Rept. 23, 1966.
4. Freyermuth, C. L., Klieger, P., Stork, D., and Wenke, H. N. Durability of Concrete Bridge Decks: A Review of Cooperative Studies. Presented at the 49th Annual Meeting and to be published in Highway Research Record 328.
5. Spellman, D. L., and Stratfull, R. F. Chlorides and Bridge Deck Deterioration. Presented at the 49th Annual Meeting and to be published in Highway Research Record 328.
6. Hearst, P. J. Deicing Materials for Military Runways. U.S. Naval Civil Engineer Laboratory, Port Hueneme, Calif., Tech. Memo M-124, March 1, 1957.
7. Hovey, G. E., Caird, J. C., and Dalby, G. A. 1966-67 Urea Test Program. Central Experimental Proving Establishment, Ottawa, Ontario, Rept. 1958, Nov. 1967.
8. Feiler, W. A. A Study of Cost, Ice Melting, and Corrosion Characteristics of Several Chemical Deicers. Monsanto Co., Inorganic Chemicals Div., Research Dept., St. Louis, Spec. Rept. 6573, Jan. 5, 1966.
9. Harris, J. C. Gibson, J. R., and Street, C. Chemical Means for Prevention of Accumulation of Ice, Snow, and Slush on Runways. Monsanto Research Corp. Final Rept. SRDS 65-13, March 1965.
10. Hanes, R. E., Zelazny, L. W., Blaser, R. E. Effects of Deicing Salts on Water Quality and Biota: Literature Review and Recommended Research. NCHRP Rept. 91, 1970.
11. Sauer, G. On Damages by Deicing Salts to Plantings Along the Federal Highways. News Journal of the German Plant Protection Service, Vol. 19, No. 6, 1967.
12. Burton, E. F., and Peaslee, D. E. The Effect of Rock Salt Upon Roadside Sugar Maples in Connecticut. Highway Research Record 161, 1967, pp. 121-131.
13. Nelson, G. A. Corrosion Data Survey. National Assn. of Corrosion Engineers, Houston, 1967.
14. California State Department of Public Health Study on Toxicity of Nitrates in Drinking Water From Wells on Infants Less Than 6 Months of Age. Sacramento Bee, Calif., Oct. 16, 1969.

Informal Discussion

William N. Records

The Bureau of Public Roads is a cosponsor of this research on bridge deck icing. We are sponsoring and cosponsoring a number of research projects on preferential bridge deck icing. We have come to realize that all of these projects are based on the premise that bridge decks do experience preferential icing on many occasions and that, when this occurs, they have accident rates significantly higher than those of other sections of roadways. Unfortunately, we do not have any facts to prove this premise. We would like to know whether anyone has any facts that show the relative occurrence of preferential bridge deck icing and the accident rates on these bridge decks.

Lawrence H. Chenault

What was your experience with heated bridges, that is, the enclosed insulated area without heat, and what was the actual effective cost and performance of the heated areas?

Don L. Spellman

The heated portions did defrost more effectively. The unheated and enclosed sections did not show any improvement over those left open. There was quite a time lag between the time we turned on the heat and the time the deck surface temperature began to rise, but this was probably due to the fact that we were using air in a convection system. We also tried heating a metal deck bridge. We have an orthotropic bridge in which we installed a gas heater for this purpose. Unfortunately, we have had little frost form on this bridge during the past 2 winters so we do not have a great amount of experience.

Glenn G. Balmer

What did you use for sealing the bridge deck? Do you have evidence that it prevented penetration of your anti-icing agent?

Spellman

We are trying several different bridge deck sealant systems now on a full scale, including not just epoxy type sealants but also rubber. Four were reported on here at this Symposium. What we are trying to find out is what evidence do we have that the sealants are not leaking. We are doing some laboratory testing by compacting various types of AC mixes over sealants because we are going to overlay these seals with a wearing course. The overlay will probably be an ordinary plant mix surfacing, but there is also an epoxy asphalt concrete that looks very good and can be put down in a much thinner layer. This makes our bridge people happy because they do not have as much dead load to deal with. We have compacted various mixes over these membranes and then tested them for permeability, and we do get puncturing when we use large rock (3/4 in.) but not when we use small (3/8 in.) rock. It appears that when we use the smaller gradation we do not get any puncturing of the membrane. We are testing for leakage by permeability.

Thad M. Jones

Do you think that, if there is a high likelihood of frost occurring, an hour's advance warning would be adequate to get your crews out?

Spellman

Not always, because they would have to be on standby, waiting in the maintenance station on weekends. An hour certainly would not give them time to cover the number of miles that they have to cover and do their work.

Jones

This would be on a selective basis because all bridges would not ice simultaneously.

Spellman

How are we going to know which ones will ice first? I think it is possible to establish areas of finite sizes, put an ice detection system on the worst bridge, find out which one usually ices first, and use that as a guide to cover the area, maybe a hundred square miles, depending on the geographical layout.

Jones

I had particular reference to the system used in the United Kingdom in which an individual warning device on bridge approaches or on the bridge deck activates an alarm in the central station indicating that a particular bridge is in an incipient icing condition and that if the temperature falls 1 or 2 deg it will have frost.

Spellman

You mean have a warning device on every bridge?

Jones

That would be nice.

Spellman

That would work as an alternative. We felt that we could do our maintenance work with long-lasting chemicals. Incidentally, this chemical I mentioned is fairly sticky. It is amazing how long it will stay in contact with the concrete and remain effective. We spread it on one bridge and 2 weeks later the maintenance people reported that the part that was sprayed had no frost or ice on it and the other part did. So our approach has been to have the maintenance people put this chemical on during their regular working hours and to avoid trying to guess when the frost is going to occur.