

INFLUENCE OF DEICING SALT ON CONCRETE STRUCTURES IN JAPAN

(Translation from Journal of Materials, Concrete Structures and Pavements,
No. 490/V-23 published by JSCE, May 1994)

Working Group on Deicing Salt,
Committee on Concrete Research Activities,
JSCE Committee on Concrete



Takashi MIURA, Chairman

Members

Hideo IKENOUE	Makoto KAWAKAMI
Masami SHOUYA	Shuuji TAKAKU
Masanao TOMON	Tadakatsu HARA
Tadashi FUJIWARA	Toyoaki MIYAGAWA

Our working group actually investigated the level of impact caused by deicing salt on road structures in Tohoku district, which, among all other concrete structures in Japan, especially seem to be greatly influenced by the use of deicing salt. From the obtained results of the studies, we projected the future deterioration, considered the necessary countermeasures to be taken and made a report. We would like to summarize here the major parts of them. The types of deterioration caused by deicing salt, that are considered here are: corrosion of reinforcing bars, frost damage on concrete and alkali-aggregate reaction.

Keywords: deicing salt, deterioration of concrete structures, corrosion, frost damage, alkali-aggregate reaction

Takashi MIRUA is a professor in the Department of Civil Engineering at the University of Tohoku, Sendai, Japan. His research interests include durability of concrete structures, properties of reinforced concrete at very low temperatures and influence of deicing salt on the concrete structures.

1. INTRODUCTION

Deicing salt has been used mainly in cold regions to thaw accumulated snow on roads or to prevent freezing on road surfaces. Recently in Japan studded tires, used for preventing car slips on icy roads, have been increasingly prohibited for reasons that they scrape road surfaces and produce fine particles, so that the use of deicing salt has been growing year by year and is expected to grow further into the future.

On the other hand, it is well known that deicing salt, whose chief ingredient is chlorides (calcium chloride and sodium chloride for the most part), causes a variety of deterioration to concrete structures. In northern Europe, northern America and Canada, where deicing salt has been used in quantity, such deterioration has surfaced and posed a big problem since more than 10 years ago, and various countermeasures have already been taken against it.

The deterioration of concrete structures caused by chloride usually occurs when chlorides have been accumulated for such a long time as to surpass a certain level, so that usually a significant amount of chloride has already been unretrievably accumulated in the concrete when deterioration begins. Therefore, this type of deterioration needs to be provided against with some countermeasures in advance, before it actually occurs in quantity.

Considering the circumstances mentioned above, our working group actually investigated the level of impact caused by deicing salt on road structures in Tohoku district, which, among all other concrete structures in Japan, especially seem to be greatly influenced by the use of deicing salt. From the obtained results of the studies, we projected the future deterioration, considered the necessary countermeasures to be taken and made a report. We would like to summarize here the major parts of them.

The types of deterioration caused by deicing salt, that are considered here, are: corrosion of reinforcing bars, frost damage on concrete and alkali-aggregate reaction.

2. STATE OF DETERIORATION AND COUNTERMEASURES IN THE UNITED STATES

It is well known that the deterioration of concrete structures from the use of deicing salt has already been emerging significantly in the United States. Therefore, we first attempted an investigation into the specific state of this deterioration from the use of deicing salt, such as the total sum of damages from the deterioration of structures or the number of structures that required remedies or restorations as well as into the countermeasures to be taken. In the documents available in Japan, we could find records in the mechanism by which deterioration occurs, or on the methods for the prevention of deterioration, that were studied abroad, but no information on such matters as the total sum of damages or the cost of remedies and restorations as mentioned above.

In view of such state of affairs, we directly asked the concrete laboratories of two universities, 1) the University of California, San Diego and 2) Northwestern University (Illinois), for the introduction of information on matters such as the total sum of damages on concrete structures from deterioration caused by the use of deicing salt. Furthermore, we also asked 3) the American Concrete Institute (ACI) for the same information.

At present, we have only received answers from the University of California, San Diego, and ACI both of whom stated that they do not have any specific information on the total sum of damages from deterioration caused by the use of deicing salt, nor on the status of remedies of concrete structures. However, the University of California, San Diego, introduced us the Department of Transportation, the State of California, so that we could obtain the following

On highways in California, as a result of the use of deicing salt since the beginning of the year 1960, the problem occurred about 10 years later concerning the severe deterioration of road slabs. In 1975, a careful investigation was conducted of bridges that had received deicing salt spray, and the cost was calculated as approximately 125 million dollars (approximately 275 million dollars $\approx$ 30 billion yen in today's money) for the restoration and remedy of deteriorations. Nowadays, damages for the use of deicing salt are reduced to the minimum by adopting protection films or cathodic protection system, or by using epoxi-coated reinforcing bars.

This was about the damages that occurred in California (presumably limited only to northern California where it snows), and more damages will be reported if investigations should be conducted over the whole country, especially the northern part. Thus, informations have not been available concerning the total sum of damages on concrete structures caused by the use of deicing salt, as well as their remedies, presumably because these problems are usually treated as directly executive matters.

3. INVESTIGATION OF THE SALES RECORD OF DEICING SALTS

Along with the investigation of the employment record of deicing salt directed to the users (state, the Japan Highway Public Corporation, prefectures and municipalities), we also conducted one directed to the sellers concerning their sales records. Since no association is formed for the sales of deicing salt, we directly asked four major companies, which were considered to be the main dealers, about the state of their sales. Furthermore, based on the answers for the three who replied, we made a report on the sales record of deicing salt, i.e. calcium chloride or sodium chloride, but this will not be discussed here.

4. QUESTIONNAIRE ON THE USE OF DEICING SALT

4.1 Purpose

Almost nothing has been reported in Japan on the state of using deicing salt which aims at preventing the freezing of road surfaces and promoting thawing of snow and ice on them. It can be anticipated that deicing salt will affect concrete in various ways, as it contains a lot of chlorides or some alkali constituents.

This questionnaire was carried out, with the time limit for answer being set at March 1989, for approximately 650 public institutions in Tohoku district, namely the national road maintenance offices of the Tohoku Bureau and the Hokuriku Bureau (only Niigata) of the Ministry of Construction, the managerial offices of the Japan Highway Public Corporation in Tohoku district, prefectural construction offices and road maintenance related sections of municipalities.

4.2 Content of the Questionnaire

The questionnaire set the following items to be answered: i) whether or not deicing salt had been used; ii) the starting year of the use of deicing salt and the record of using it for the past three years; iii) standard for the use of deicing salt (conditions, standard amount, places, main constituents and brand names); iv) state of using deicing salt in the year 1989 (total amount, total distance of road and amount used according to the month).

Table-1 Standard Amount of Spray

the Japan Highway Public Corporation	30g/m ²
the Ministry of Construction	30g/m ² (20~ 40g/m ² in some rare cases)
Prefectures	Niigata 40g/m ² , the others 20~ 150/m ² , but mostly around 40~ 50m ² .
Municipalities	40~ 1500g/m ² mostly deterined by judgment at site.

4.3 Results

Against 658 questionnaires delivered, the number of answers obtained was 448, and the recovery rate was about 68%.

4.3.1 Whether or Not Deicing Salt Had Been Used

Deicing salt had been used at all the branch offices of the Ministry of Construction, the Japan Highway Public Corporation and the prefectural governments, and its employment rate there was 100%. Quite a lot of unevenness was observed among the municipalities depending on the region(prefecture) they belong to. The average employment rate of deicing salt in cities was 69%, in towns and villages around 37%, and it was found that the employment rate generally decreased from cities to towns, and from towns to villages. Furthermore, when observed according to the prefecture, there were many offices that used deicing salt in Iwate and Miyagi prefectures, while there were much fewer in Yamagata prefecture. The average rate of all these came out too be around 55% (number of deicing salt users/total number = 241/436).

4.3.2 Starting Year of using Deicing Salt

The starting years of deicing salt using offices were in the following order: municipalities, prefectures, the Ministry of Construction and the Japan Highway Public Corporation. Most cases of the Ministry of Construction were started before 1982. Of all the cases, about 60% in average was started before 1982. The number of cases that were started after 1985 was only 10 in total, which indicates that in most cases more than 5 years had passed since the use of deicing salt had been started. There were several cases whose starting year was 1965.

4.3.3 Standard for Using Deicing Salt

1) Judging Standard for the Determination to Use Deicing Salt.

All the branch offices of the Ministry of Construction and of the Japan Highway Public Corporation had their own judging standards to determine to use deicing salt. Furthermore, 75% of the prefectural construction offices and 41% of the municipalities had some kind of standard for the determination.

Most of them set the following specific items:

- i) When freezing is projected or observed by patrols or forecasts.
- ii) When there is a fear of car slips in places where the compacted snow is expected to turn into ice plate, or where the road is in a wet condition. In some cases the use of deicing salt is determined according to the depth of accumulated snow.
- iii) When there is any report from the residents.
- iv) Places where the gradient is 3~5%, shadowy places and intersections are taken seriously.

2) Setting of the Standard Amount of Spray

The standard amount was set in 100% of the offices of the Japan Highway Public Corporation, 97% of those of the Ministry of Construction, 74% of prefectural construction offices and 13% of the municipalities. The standard amount of spray are shown individually in Table-1. The Japan Highway Public Corporation and the Ministry of Corporation had their standard amount set at 30g/m². In municipalities there was a great variety in their level of setting, and there were many unclear points.

3) Method of Using Deicing Salt

The Japan Highway Public Corporation used specific cars for spraying deicing salt, whereas the Ministry of Construction mostly used either specific cars or trucks, and the prefectural construction offices also used either specific cars or trucks when they have a lot of deicing salt to spray, but 37% of their answer also stated that they sprayed deicing salt in walking. In municipalities the mainstream method was to spray in walking, which made up 64% of their total.

4) Types of Deicing Salt and Their Ratio

The Japan Highway Public Corporation had been using calcium chloride(CaCl₂) for the cold regions north of Furukawa, while using sodium chloride(NaCl) in the warmer regions to its south. However, NaCl was increasingly used, since the monopoly restriction for the latter had been abolished and its cost now became only about 1/1.8 of the former. NaCl was adopted in 96% of the cases related to the Ministry of Construction. NaCl-type deicing salt was used in 65% of prefectural cases, whereas CaCl₂ was used in about 85% of municipalities. As to urea-type deicing salt and MgCl₂ magnesium chloride, the former was only used in 1 case and the latter in 2 cases. There were also some cases where the combination of NaCl and CaCl₂ was used. As a whole, the number of branch offices using CaCl₂ accounted for slightly less than 64% and was double the number of those using NaCl.

4.3.4 Record of the Employment of Deicing Salt in 1989

1) Total Amount of Spray

The total amount of spray Q varies according to the total distance of road sprayed with deicing salt, and is given in Table-2 according to the users: the Japan Highway Public Corporation, the Ministry of Construction and the prefectural governments. The total amount of spray of one branch office of the Japan Highway Public Corporation was 766ton in average, the corresponding amount of spray for the Ministry of Construction was 102ton, and that for prefectural construction office was 49ton. The order of amount of spray according to individual prefectures was: Niigata > Miyagi > Yamagata, Aomori and Akita > Fukushima and Iwate. It can be concluded from these results that 20,000 ton of

Table-2 Record of Spray in 1989

	Niigata (ton)	Yamagata (ton)	Fukushima (ton)	Miyagi (ton)	Iwate (ton)	Akita (ton)	Aomori (ton)	Total (ton)
the Japan Highway Public Corporation (Average)	— ()	176 (176)	2373 (1187)	2419 (1210)	2226 (742)	931 (931)	700 (350)	8825 (766)
the Ministry of Construction (Average)	2840 (258)	305 (76)	254 (51)	— ()	421 (53)	546 (96)	215 (84)	4617 (102)
Prefectures (Average)	2129 (125)	219 (73)	— ()	605 (76)	144 (16)	181 (30)	323 (46)	3601 (49)

Table-3 Amount of Spray per Distance (Q/L:t/km)

	Niigata (t/km)	Yamagata (t/km)	Fukushima (t/km)	Miyagi (t/km)	Iwate (t/km)	Akita (t/km)	Aomori (t/km)	Average (t/km)
the Japan Highway Public Corporation	—	0.26	0.10	0.17	0.11	0.04	0.09	0.12
the Ministry of Construction	0.55	0.09	0.17	—	0.17	0.16	0.13	0.21
Prefectures	0.64	0.29	—	0.41	0.80	0.98	0.21	0.41
Municipalities	0.72	0.28	0.80	0.52	1.58	0.48	1.08	0.75

deicing salt was used in total in Tohoku district(except Niigata) by prefectural governments, the Ministry of Construction and the Japan Highway Public Corporation.

2) The Amount of Spray of Deicing Salt per 1km Distance

The amount of spray deicing salt per distance Q/L is shown in Table-3. From this we can observe that Q/L for the Japan Highway Public Corporation and the Ministry of Construction were about 0.12~0.14ton/km in the six Tohoku prefectures except Niigata, while for municipalities the ratio was 5~6 times as large. In some cases the ratio was more than 10 times as large. Furthermore, the amount of spray in Niigata prefecture was a little less than 4 times as large as in other prefectures in cases related to the Ministry of Construction, a little less than 2 times as large in cases of prefectural construction offices and about the same in cases of municipalities, which indicates that quite a lot was used in this prefecture. The order of the amount of spray according to the individual prefecture was broadly as follows: Niigata >Iwate and Akita > Miyagi, Fukushima and Aomori > Yamagata.

5. MEASUREMENT OF CHLORIDE CONTENT IN REAL STRUCTURES

We took samples from real concrete structures in various parts of Tohoku where deicing salt was used, and measured the chloride content in them. Part of the results will be shown in the Fig.1~3. Here, the chloride content is shown as the weight percentage of chloride ion against concrete. Furthermore, the level of the permeation of chlorides was studied by sampling from the surface or the side of the structures.

6. PROJECTION OF FUTURE DETERIORATION

Judging from the results of the investigation of the sales and usage record of

Cl⁻ Content of Concrete-Blocks on Roads

Location: Namioka-cho, Aomori Prefecture
(National Highway No.7)
with vertical gradient of less than 3%

Sample: Concrete-Block Border between
Sidewalk and Roadway

Years Passed: Over 10 Years

Use of Deicing Salt: Since before 1982, approx. 60 times/y

Standard Usage: 30g/m²

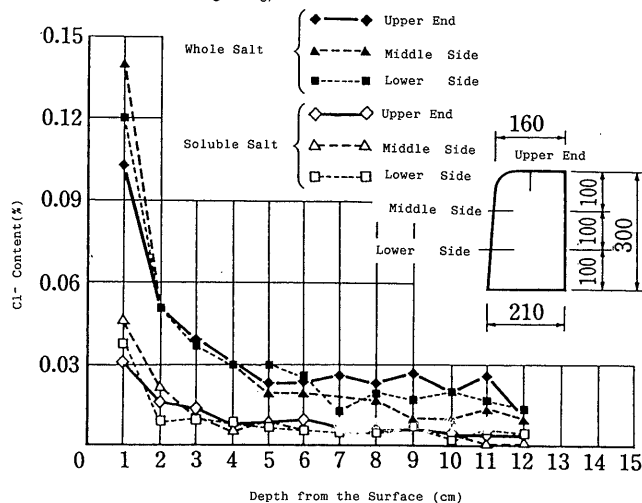


Fig.1 Measured Chloride Content (a)

deicing salt, we can say that a considerable amount of deicing salt has already been used in Japan. Besides, quite a lot of unevenness is observed in the amount used; especially for some municipal roads the standard for the amount of spray is nearly 50 times as large as that for national roads, so their situation must presumably be dangerous in some places. Furthermore, the results from the chloride content structures, and that the accumulation has already proceeded to the depth of 8cm from the surface of old ones. Moreover, in some cases reinforcing bars have corroded and the cover concrete already come off. Based on the above results of the investigation, the projection of future deterioration is given in the following according to its type.

6.1 Corrosion of Reinforcing Bars in Concrete Structures

It became evident that deicing salt has already begun to accumulate in broad areas of the concrete, and has been spreading deeper year by year. Therefore, it is already clear that before long the corrosion of reinforcing bars in concrete will pose a big problem. Especially in the case of local roads where the method of using deicing salt is still undeveloped, some concrete structures have already developed the corrosion of reinforcing bars because of the intensive spray of deicing salt on some spots.

6.2 Frost Damage

Frost Damage of concrete suffering the impact of deicing salt is mainly the surface scaling of concrete. This has already occurred on many road structures,

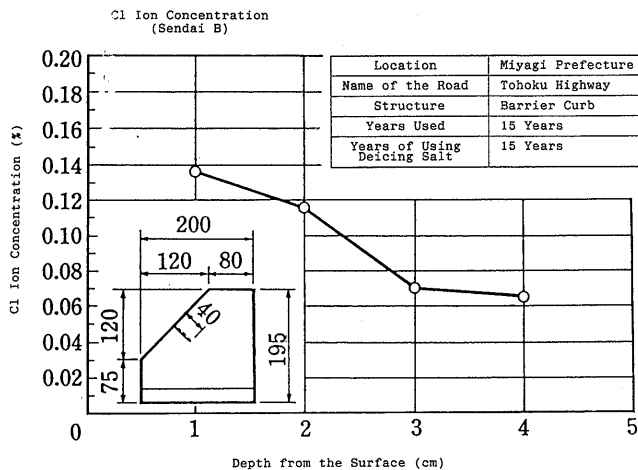


Fig.2 Measured Chloride Content (b)

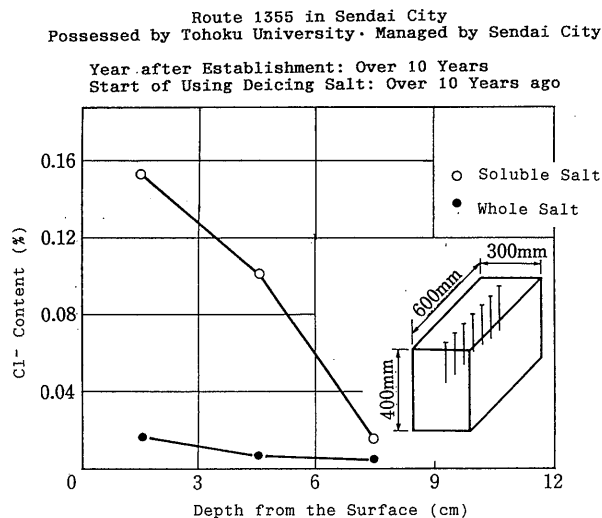


Fig.3 Measured Chloride Content (c)

among which the worst are the cases of precast products of concrete. As to civil engineering structures in general, damages are limited to some parts of badly constructed structures or to the portions where drainage has come to stream down the surface of structures. however, since most of the concrete used in the past was mixdesigned and constructed without consideration to the impact of deicing salt, these deteriorations might worsen if left as they are.

6.3 Alkali-Aggregate Reaction

When sodium chloride is used as deicing salt, it might cause an alkali-aggregate reaction depending on the aggregate used. the point which will require special

attention is that some of the concrete that was regarded usable under a normal environment might predictably become dangerous. The presence of this possibility also became evident from the results of the research conducted to clarify this point along with the investigation.

6.4 Other Deteriorations

When calcium chloride is used as deicing salt, it is said that a specific expansion deterioration might occur even in the concrete with a small water-cement ratio. This was already made clear around 1968, and it is foreseeable enough that this type of deterioration will also surface in the future Japan.

7. COUNTERMEASURES TO BE TAKEN IN THE FUTURE

Judging from the above results of the investigation, it is assumed that following countermeasures will be necessary for concrete structures which should suffer the impact of deicing salt.

Against the corrosion of reinforcing bars, such consideration will be needed in advance, when building concrete structures, as using epoxi-coated reinforcing bars.

Against the frost damage of concrete, we should perfectly obey the rules of the standard specification for design and construction of the concrete structures set by the Japan Society of Civil Engineers, which require to make the water-cement ratio small and the air content large in all the concrete that will suffer the impact of deicing salt. As to the type of deicing salt to be adopted, a policy change to use sodium chloride will be needed as much as possible.

Besides, what we refer to here as countermeasures against alkali-aggregate reaction are not the ones to be adopted for the structures under a general environment, but for the structures under NaCl environment.

8. CONCLUSION

With this investigation we tried to clarify the impact of deicing salt on the deterioration of concrete structures. However, since the time as well as the scope of the investigation was limited, we could not obtain sufficiently precise results.

Nevertheless, we consider that at least we could make it clear that the problem of deterioration of concrete structures caused by the use of deicing salt will also surface in future Japan, and that it is required to continue the further consideration of this problem and to adopt some countermeasures as soon as possible.