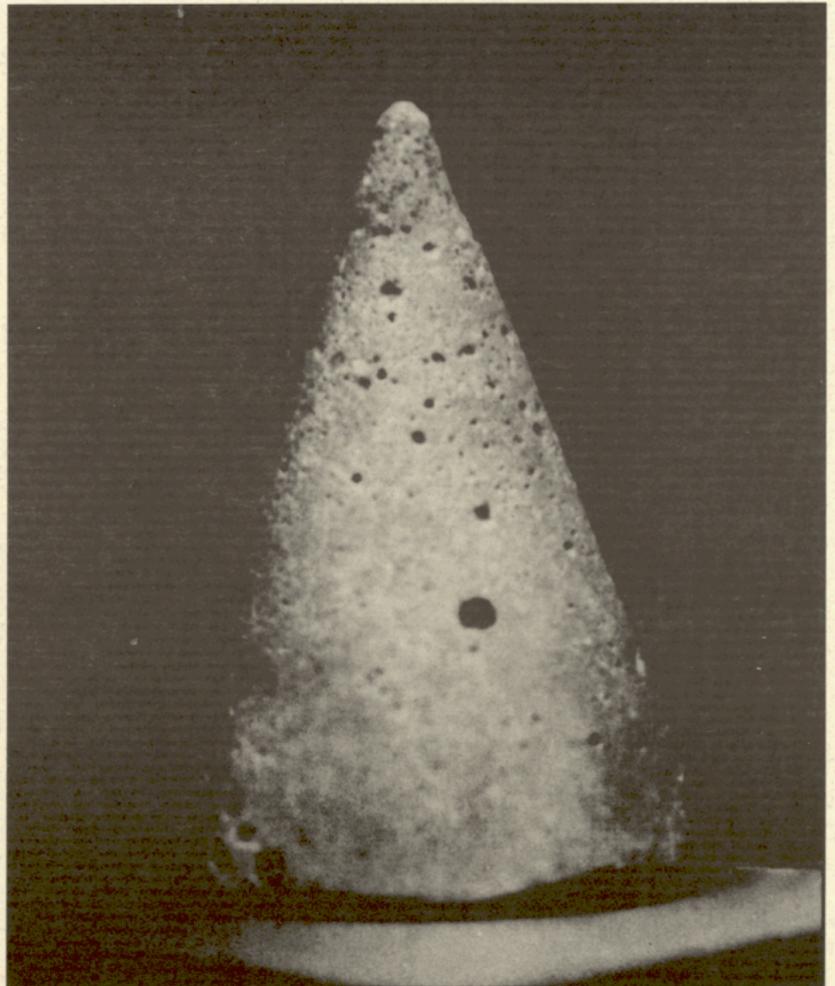


Physical Research



# Effect of Salt Additives on Concrete Degradation





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# EFFECT OF SALT ADDITIVES ON CONCRETE DEGRADATION

Final Report - Executive Summary

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## SUMMARY

In a previous investigation, it was found that the corrosion-inhibited deicing salts provide enough chemical elements to cause the degradation of concrete by both anionic and cationic constituents. The precipitates resulted from chemical reactions between the concrete and the corrosion-inhibited deicing salts, and dramatic pH changes were found in the concrete-saturated solution mixed with the corrosion-inhibited deicing salts. However, the effect of the corrosion-inhibited deicing salts on the concrete degradation is not well understood, and methods for determining the effect of the corrosion-inhibited deicing salts on concrete degradation are not available. In this investigation, an attempt was made to develop methods to determine the degree of the concrete degradation caused by corrosion-inhibited deicing salts and the factors influencing the concrete degradation.

Cone-shaped concrete samples were fabricated to accelerate the deterioration of the concrete by providing a large exposed surface area to the corrosion-inhibited deicing salt solutions. The varying diameter enables quicker penetration at the top portion of sample. Six corrosion-inhibited deicing salts and plain sodium chloride were mixed into deionized water at 3, 6 and 20%.

After immersing the concrete samples in the 3, 6 and 20% corrosion-inhibited deicing salt solutions for a day, various amount of precipitates were observed on the concrete sample surfaces and/or at the bottom of the test cells depending on the type and the concentration of corrosion-inhibited deicing salts. However, no precipitates were observed in the test cells containing NaCl, city water and deionized water. The amount of the precipitates appears to increase as a function of time.

The chemical changes of the test solutions as well as the physical changes of the concrete samples are being monitored as a function of time. The results collected so far provide clear evidence of the chemical reactions between the concrete and the corrosion-inhibited deicing salts. The impact of the chemical reactions on the concrete degradation can be understood by determining (i) chemical and mineralogical changes of the concrete caused by the corrosion-inhibited deicing salts, (ii) the effect of precipitates on pH changes of the concrete and on concrete degradation.



The physical changes of the concrete sample are not significant enough to date to determine the dimension changes by the corrosion-inhibited deicing salt solutions. Thus, further investigation is recommended until significant physical changes of the concrete samples are observed. The precipitates should be collected from the test cells for quantitative and qualitative analysis to identify the degree of chemical reactions and the chemical elements involved in the reactions. The measurements of volume changes when the wet-precipitates are dried may determine the impact of precipitates on micro-cracks inside of concrete.



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## CHAPTER 1. LITERATURE REVIEW

Concrete degradation may occur through a variety of chemical and physical processes. This review deals with the chemical process in which cement paste and deicing salts are involved.

It is well known that the use of deicing salts causes rebar corrosion in concrete and leads to structural failures. However, the effect of deicing salts on concrete degradation is not well understood. The use of deicing salts may cause surface damage by scaling. The suggested causes of the surface damage include rapid cooling caused by the melting of ice, osmotic effects associated with the presence of high concentrations of deicing chemicals in the surface layer of concrete, and chemical attack by chloride ions. In the results of our research project titled, "Effect of Salt Additives on Rebar Corrosion" (Sponsor:MN/DOT), it appeared that the chemistry of deicing salts causes deterioration of the concrete. Literature on general concrete degradation and concrete degradation by deicing salts has been reviewed.

### 1. CONCRETE DEGRADATION.

The three principal types of concrete degradation may be distinguished by their prevalent signs of destruction(1-4);

**Type I** is the decomposition of concrete by the action of aqueous solutions able to dissolve the ingredients of the hardened cement. When dissolved, the components are removed by leaching from the structure of the concrete.

**Type II** embraces exchange reactions, i.e. chemical reaction including cation exchange between the hardened cement constituents and a solution. Easily soluble reaction products are removed from the internal structure of concrete by diffusion or by percolation.



**Type III** involves the accumulation, crystallization and polymerization of chemical reaction products which increase the volume of the solid phase within the pore or capillary structure of concrete. Crystallization and other secondary processes occurring in concrete create internal stresses which may lead to the structural failure of concrete.

A summary of the types of concrete deterioration is presented in Table I, in which the definition, phenomena, mechanism, factors influencing the rates of deterioration and the effects of chemical elements on the three types of deterioration are given. Deterioration by a single Type rarely occurs in nature. In addition to the principal Types of deterioration, the secondary Types always contribute to accelerate the deterioration of concrete.

The chemistry of the deicing salts (Table II) suggest that the concrete would deteriorate in the Types described in Table I, especially via Types II and III. The amount of  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ ,  $\text{SO}_4^{2-}$  and  $\text{Cl}^-$  in Table II may be large enough to react with certain chemical components in concrete. Even though the role that  $\text{PO}_4^{3-}$  in the degradation of concrete is not yet known, there is a possibility of chlor-apatite ( $\text{Ca}_5(\text{Cl})\text{PO}_4$ ) formation in concrete(5).



Table 1. Types of deterioration of concrete

	Type I	Type II	Type III	
Definition	Decomposition of concrete by action of liquid (or Lime leaching)	Exchange reaction (or chemical reaction) between hardened cement constituents and a solution	Accumulation, crystallization and polymerization of reaction products	
Phenomena	<ul style="list-style-type: none"> <li>• Dissolve ingredients of hardened cement</li> <li>• pH value of concrete is reduced</li> </ul>	Easily soluble reaction products are removed from concrete internal structure by diffusion, or may deposit as an amorphous mass which has no binding properties	Increase volume of crystallized phase with pore structure of concrete and increase internal stresses	
Mechanism	Leach out $\text{Ca}(\text{OH})_2$ formed by carbonation from mass of concrete	Precipitates of $\text{Mg}(\text{OH})_2$ and $\text{CaSO}_4$	Precipitates and crystal growths of gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) and ettringite ( $3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{CaSO}_4 \cdot 12\text{H}_2\text{O}$ )	
Factors influencing rate of deterioration	<ul style="list-style-type: none"> <li>• Permeability of concrete</li> <li>• Content of calcium oxide or hydroxide</li> <li>• Mineral composition of cement clinker</li> <li>• Temperature</li> </ul>	<ul style="list-style-type: none"> <li>• Solubility of calcium salt</li> <li>• Temperature</li> </ul>	<ul style="list-style-type: none"> <li>• Wet-dry cycle</li> <li>• Freeze-thaw cycle</li> <li>• Temperature</li> </ul>	
Effect of chemical elements	$\text{Ca}^{++}$	Decreases solubility of $\text{Ca}(\text{OH})_2$	Interact with $\text{MgSO}_4$ or $\text{MgCl}_2$ to form $\text{CaSO}_4$ or $\text{CaCl}_2$	Decrease solubility of $\text{CaSO}_4$ , then invites $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$
	$\text{K}^+$	Increases solubility of $\text{Ca}(\text{OH})_2$	--	--
	$\text{Mg}^{++}$	Small quantities of Mg ions tend to retard dissolution by transforming $\text{Ca}(\text{OH})_2$ to $\text{Mg}(\text{OH})_2$ . $\text{Mg}(\text{OH})_2$ deposits on surface layer and decrease the permeability of concrete	<ul style="list-style-type: none"> <li>• Interact with <math>\text{Ca}(\text{OH})_2</math> to form <math>\text{Mg}(\text{OH})_2</math> precipitate</li> <li>• <math>\text{Ca}^{++}</math> as a binding agent of concrete may be replaced gradually by <math>\text{Mg}^{++}</math></li> </ul>	Increase MgO, then decrease sulfate resistance
	$\text{Na}^+$	Increase solubility of $\text{Ca}(\text{OH})_2$	Increase extraction of $\text{SiO}_2$ , $\text{CaO}$ and $\text{Al}_2\text{O}_3$	$\text{Na}^+$ in $\text{NaCl}$ retards precipitates by increasing solubility of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$
	$\text{SiO}_3^-$	--	--	--
	$\text{PO}_4^-$	--	--	--
	$\text{SO}_4^-$	Increase solubility of $\text{Ca}(\text{OH})_2$	Increase reaction of $\text{MgSO}_4$ to form $\text{Mg}(\text{OH})_2$ precipitate	Promotes formation of gypsum and ettringite
	$\text{Cl}^-$	<ul style="list-style-type: none"> <li>• Increase solubility of <math>\text{Ca}(\text{OH})_2</math></li> <li>• <math>\text{Cl}^-</math> in <math>\text{MgCl}_2</math>, not <math>\text{NaCl}</math> or <math>\text{KCl}</math>, reacts with lime and form unstable and water-soluble compound</li> </ul>	<ul style="list-style-type: none"> <li>• <math>\text{Cl}^-</math> in <math>\text{MgCl}_2</math> accelerates formation of <math>\text{Mg}(\text{OH})_2</math> precipitate</li> <li>• <math>\text{Cl}^-</math> in <math>\text{NaCl}</math> increases solubility of <math>\text{Mg}(\text{OH})_2</math></li> </ul>	$\text{Cl}^-$ in $\text{NaCl}$ and $\text{CaCl}_2$ increases solubility of ettringite
	Remark	<ul style="list-style-type: none"> <li>• <math>\text{CaCl}_2</math> retard leaching because of common cation in <math>\text{Ca}(\text{OH})_2</math> and <math>\text{CaCl}_2</math></li> <li>• <math>\text{Ca}(\text{OH})_2</math> aggravates ASR</li> </ul>	$\text{Mg}(\text{OH})_2$ precipitates are slightly soluble, so may be an obstacle to the diffusion of $\text{SO}_4$ ions and retard sulphate reaction	



Table II. Chemistry of corrosion-inhibited deicing salts used in the previous research

Element	Percentage
Ca <sup>++</sup>	0.35 ~ 20.00
K <sup>+</sup>	0.01 ~ 0.39
Mg <sup>++</sup>	0.01 ~ 3.68
Na <sup>+</sup>	0.57 ~ 37.00
Si <sup>++</sup>	0.00 ~ 2.13
PO <sub>4</sub> <sup>≡</sup>	0.05 ~ 9.52
SO <sub>4</sub> <sup>-</sup>	1.79 ~ 33.00
Cl <sup>-</sup>	0.79 ~ 56.25



## 2. RESEARCH ACTIVITIES ON CONCRETE DEGRADATION BY DEICING SALTS.

The effect of deicing salts on the Burlington Bay Skyway located near Hamilton, Ontario, was reported(6). After three winters, removal of asphalt for repairing the deck joints revealed salt scaling on the concrete surface, particularly at the curb lines, where the coarse aggregate particles were generally exposed.

$\text{Ca(OH)}_2$  acts as a "buffer" to maintain high pH, i.e. high  $\text{OH}^-$  ion concentration in pore solutions. The pH could fall to 8.5 or below by the leaching of  $\text{Ca(OH)}_2$ . It was speculated that the free  $\text{Ca}^{++}$  exchanged for alkali ions, and the released alkali ions produced further expanding alkali-silica complex(7).

J.E. Gillott(8) investigated the effect of soaking solutions on limestone by scanning electron microscopy and found that the surface of limestone was scaled and disintegrated when soaked in solutions of sodium chloride, calcium chloride and magnesium sulphate. The morphology of both calcite and dolomite were changed, and the reactions were controlled by cleavages and grain boundaries of calcite and dolomite. Some limestones showed dimensional changes during continued soaking in salt solutions at constant temperature. The durability of concrete involved cement paste, though aggregate makes up about 70 percent of the volume of concrete. The chemical process affected both cement paste and aggregate. The chemical processes involved in the deterioration of concrete were suggested to include leaching, crystal growth and hydration.

The effect of calcium sulfate impurities in deicing salts on the durability of portland cement mortar was investigated by J.M. Pitt(9). Small amounts of sulfate impurities in deicing brine was detrimental to durability of the concrete mortar. Maximum deterioration for the test mortar led to 40 percent loss in tensile strength. Mechanisms for sulfate-enhanced chloride deterioration were thought to be void-filling from the formation of Friedel's salt (tricalcium aluminate chloride hydrate) and ettringite. Friedel's salt formation also appears to be enhanced by the presence of gypsum.

C.F. Crumpton(10) reported that the deicing salts exacerbated the alkali-aggregate reaction, D-cracking problem, and pavement blowup problem by keeping the internal concrete wet for longer periods of time. Degraded illite altered into sodium montmorillonite in limestone aggregate in concrete. Sodium from the deicing



salt exchanges for potassium in the illite. The potassium, coupled with sodium and sulfate from the deicing salt, deposits as a mineral, aphthitalite( $K_3Na_2O(SO_3)_4$ ) along with thernardite( $Na_2SO_4$ ).

The factors affecting the concrete durability were investigated by M. Gunter(11). The pore structure of hydrated cement paste was influenced significantly by the water-to-cement ratio, duration of curing, carbonation and type of cement.

The effect of salt inclusion in the Ordinary Portland Cement (OPC)/ Pulverized Fuel Ash (PFA) concrete on alkalinity and carbonation was investigated(12), and insignificant reduction in alkalinity was noted in OPC/PFA concrete due to chloride contamination.

### **3. TEST METHODS OF DETERMINING CONCRETE DURABILITY TO SALT-RELATED DETERIORATION.**

ASTM Standard C672-84(13) specifies the test method for determination of resistance to scaling of the concrete structure exposed to deicing salts under freeze-thaw cycles. It is intended for use in evaluating the chemically attacked concrete qualitatively by visual examination of such parameters as pattern of cracking, seepage, staining, softening and spalling(14).

The Iowa DOT developed an ice porosimeter to determine aggregate susceptibility to salt-related deterioration. The method of evaluation included analyses of both the pore system and chemical composition of aggregate. The aggregate chemistry was analyzed using X-ray analysis(15).



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## CHAPTER II. CONCRETE DEGRADATION BY CORROSION-INHIBITED DEICING SALTS

### 1. INTRODUCTION

Concrete may be degraded in three different ways distinguished by the prevalent signs of destruction such as (i) decomposition of concrete by action of liquid (or lime leaching), (ii) exchange reaction (or chemical reaction) between hardened cement constituents and a solution, and (iii) accumulation, crystallization and polymerization of reaction products. The corrosion-inhibited deicing salts can degrade the concrete by the three types as mentioned above, and exacerbate alkali-silica reaction, D-cracking and salt scaling of concrete.

In the results of our research project titled, "Effect of Salt Additives on Rebar Corrosion" (sponsor: MN/DOT), it was found that the corrosion-inhibited deicing salts provide enough chemical elements to cause degradation of the concrete by both anionic and cationic constituents. Also, dramatic pH changes and precipitation formation in the corrosion-inhibited deicing salts mixed concrete solutions were found, which suggested that the corrosion-inhibited deicing salts interacted with the concrete chemistry. The reason for the decrease in pH is unclear. The effect of precipitates formed in concrete by the corrosion-inhibited deicing salts on concrete degradation should be determined. If certain ions in the corrosion-inhibited deicing salts that function as inhibitors are lost by precipitation, the effectiveness of the corrosion-inhibited deicing salts on rebar corrosion could drop significantly. The formation of precipitates in concrete cracks may act as a barrier to the penetration of the salt solution, thereby acting as an inhibitor. Alternatively, some of the precipitates may form in micro-cracks or pores of concrete, and volume expansion of the dried precipitates may generate stresses, which initiate and/or propagate cracks. The pH change may cause the degradation of concrete properties such as bonding strength, and create or propagate concrete cracks over a period of time.

However, the effect of the corrosion-inhibited deicing salts on the concrete degradation is not well understood, and methods for determining the effect of the corrosion-inhibited deicing salts on the concrete degradation are not available. In this investigation, an attempt was made to develop methods to determine the



degree of the concrete degradation by corrosion-inhibited deicing salts and the factors influencing the concrete degradation. Also, the investigation is to determine (i) the chemical and mineralogical changes of concrete by the corrosion-inhibited deicing salts, (ii) the effect of precipitates on rebar corrosion, concrete degradation and pH changes of concrete, and (iii) the effect of pH changes on concrete degradation and rebar corrosion in concrete.



## **2. EXPERIMENTAL**

Cone-shaped concrete samples were designed to accelerate the deterioration of concrete in the corrosion-inhibited deicing salts solutions. The physical and chemical changes of the concrete samples are examined by visual examination and chemical analysis as well as optical and scanning electron microscopy. The chemical analysis of the test solutions before and after the test may provide the information about the chemical reactions including cation exchanges. The chemical reaction products (precipitates) will be identified by using scanning electron microscopy and x-ray analysis.

### **1) Concrete Degradation in Existing Structures**

Concrete samples, collected from construction sites, were examined for chemical and mineralogical changes of concrete through observations of the concrete surfaces and the cross-sections by optical and scanning electron microscopy.

### **2) Cone-shaped Concrete Samples**

Cone-shaped concrete samples (Figure 1(a)) were made by mixing 825 lb (374 kg) Type III cement, 1400 lb (635 kg) sand (Minnesota DOT Specification 3126) and 1400 lb(635 kg) quartzite meeting CA-70 gradation (Minnesota DOT Specification 3137). A paper mold was used for the cone-shaped concrete samples. The cone-shape of the samples was to provide a large surface area exposed to the corrosion-inhibited deicing salt solutions, and would accelerate the chemical reactions at the tip of concrete sample. The physical changes of concrete samples would be noticed at the tips easily. The concrete samples were in a moisture room for 28 days after fabrication, and then air dried. The compressive strength of the concrete samples was 9190 psi.

After the bottoms of the cone-shaped concrete samples were cut by a diamond saw under water cooling to make samples of uniform dimension, the samples were cleaned by using a Dayton 3Z856 sand blaster and Graded Ottawa Sand (ASTM C-109) under 60 psi air pressure. The distance between the sand blaster nozzle and



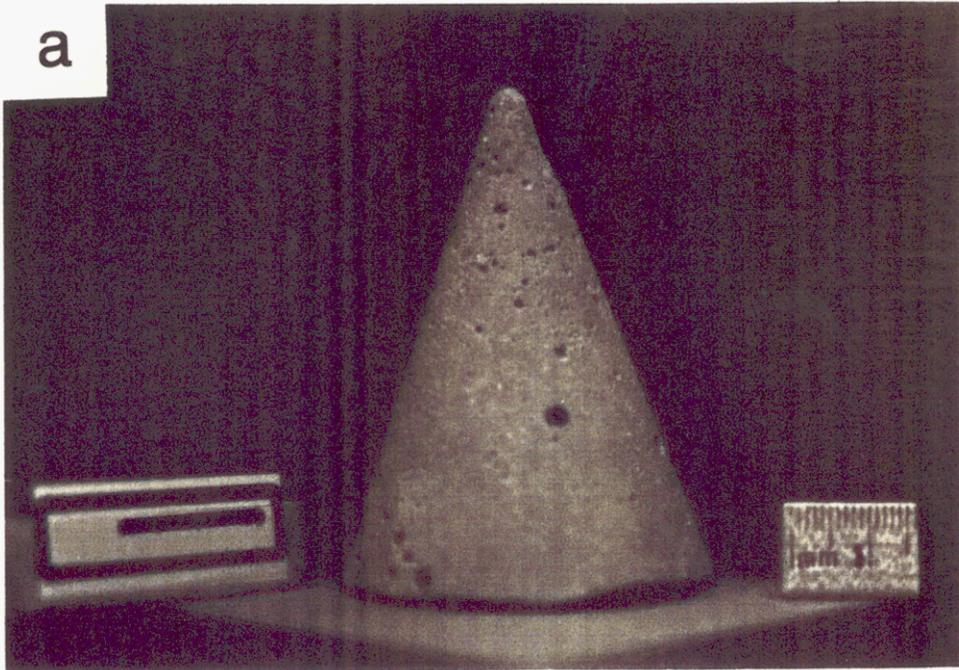


Figure 1. A cone-shaped concrete sample(a) in the test cell(b) for concrete degradation by corrosion-inhibited deicing salts.



the samples was kept constant. The average dimension of samples was 2 inch (50.8 mm) bottom diameter by 2.5 inch (64 mm) height. The initial dimension of each sample was measured using a dial caliper, and the weight was measured by a Sartorius balance. The average weight of the samples was 0.26 lb (120 gm).

### **3) Corrosion-Inhibited Deicing Salt Solutions**

Six corrosion-inhibited deicing salts and plain sodium chloride were mixed into deionized water at concentrations of 3, 6 and 20%. The corrosion-inhibited deicing salt solutions were filtered to remove the insoluble constituents.

One concrete sample was immersed into a polyethylene jar (Figure 1(b)) containing 500 ml of a corrosion-inhibited deicing salt solution. A DIONEX Series 4000i Ion Chromatography System using 2 AS4A separator columns and suppressed conductivity detection was used for anions analysis and a Perkin Elmer/Sciex Elan 5000 Inductively Coupled Plasma - Mass Spectrometer for cations before the concrete samples were immersed into the solutions. 3 ml solution samples are being collected periodically from the jars (test cells) to examine the chemical changes of the test solutions.

### **4) Chemistry of Precipitates**

The precipitates formed by chemical reactions between the concrete samples and the corrosion-inhibited deicing salt solutions were observed visually after one day of immersion. The precipitates were found at the bottom of the test cells and/or on the surfaces of cone-shaped concrete samples. The nature of chemical reactions and the identity of precipitates will be investigated after the precipitates are recovered from the test cells. The test will be terminated when significant physical changes of the cone-shaped concrete sample are visually observed.



## **5) pH Changes of Corrosion-Inhibited Deicing Salt Solutions**

pH changes in the test solutions are being monitored. A glass-Ag/AgCl micro-pH electrode is used with an Orion Model 399A pH meter. The electrode is calibrated before each measurement.



### **3. RESULTS**

#### **1) Precipitates in Concrete Samples from Field**

The concrete samples collected from a construction site were examined using an environmental scanning electron microscope. Needle-shaped precipitates were found in voids (Figure 2(b)), and on the crack wall (Figure 3(b)) of concrete. However, further investigation is necessary to identify the precipitates.

#### **2) Precipitates in Corrosion-Inhibited Deicing Salt Solutions**

The concrete samples were placed into the three, six and twenty percent corrosion-inhibited deicing salt and plain sodium chloride solutions. After leaving the concrete samples in the test solutions for a day, various amounts of precipitates were found in the test cells depending on the type and the concentration of corrosion-inhibited deicing salts (Figures 4-11). Figures 7-11 show that the precipitates were formed by chemical reactions between the concrete and the corrosion-inhibited deicing salts. The precipitates were observed on the concrete sample surfaces and/or at the bottom of test cells. However, no precipitates were found in the test cells containing NaCl, city water and deionized water as shown in Figures 4-6. Deicing Salts E and F (Figures 10 and 11) decreased the precipitates as the concentration of corrosion-inhibited deicing salts increased, while the rest of the Deicing Salts tested increased the precipitates as the concentration increased. It appears that the amount of precipitates increased with time. Deicing Salt C was not presented here because the dark color of solutions prevented to observed the samples from top.

#### **3) Chemical Changes of Corrosion-Inhibited Deicing Salt Solutions**

The chemical changes of the test solutions as well as the physical changes of the concrete samples are being monitored as a function of time. The changes of  $\text{Ca}^{++}$  concentration in the test solutions as a function of time are shown in Figures 12-14. The  $\text{Ca}^{++}$  in the solutions is decreasing or increasing depending on the type of corrosion-inhibited deicing salts. The  $\text{Ca}^{++}$  in deionized and city waters remains relatively constant to date,



while that in NaCl solution decreases as a function of time. The reason for the decrease of  $\text{Ca}^{++}$  in NaCl is not understood at this time, and further investigation is necessary to understand the chemical changes in the solutions along with the amount and the chemistry of precipitates.



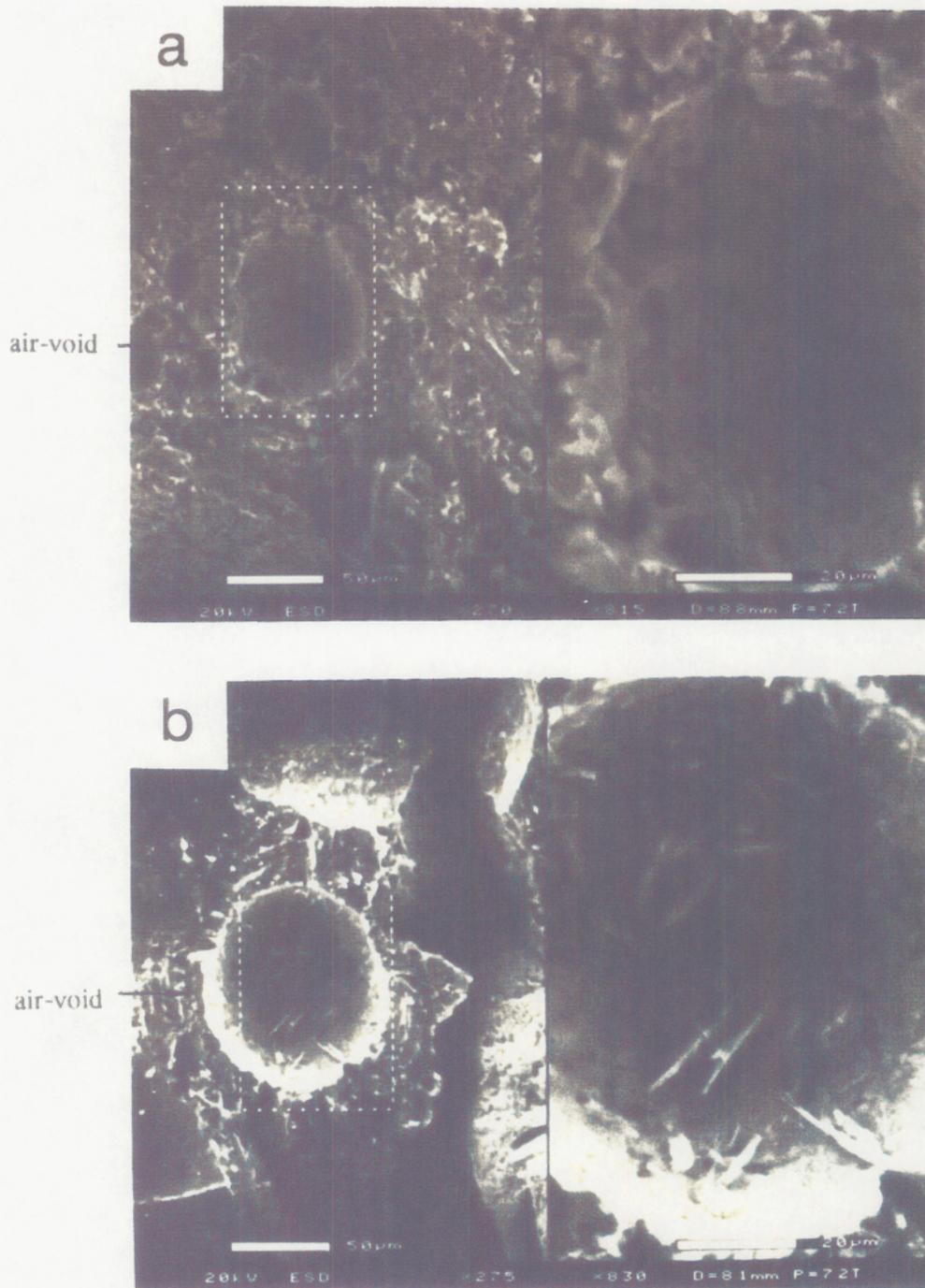


Figure 2. The needle-shaped precipitates in air-void of concrete; (a) fresh concrete and (b) concrete exposed to deicing salts at fields.



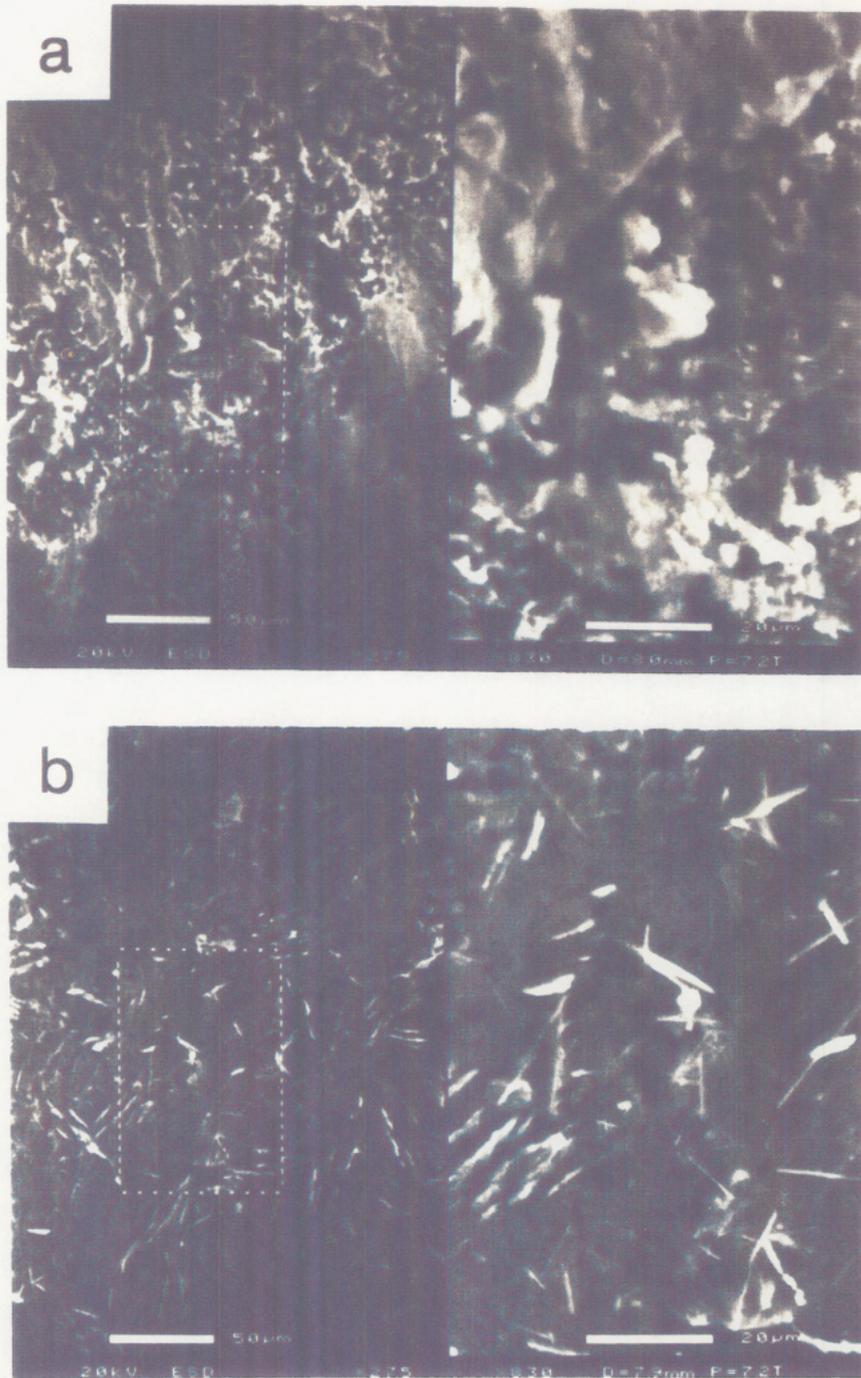
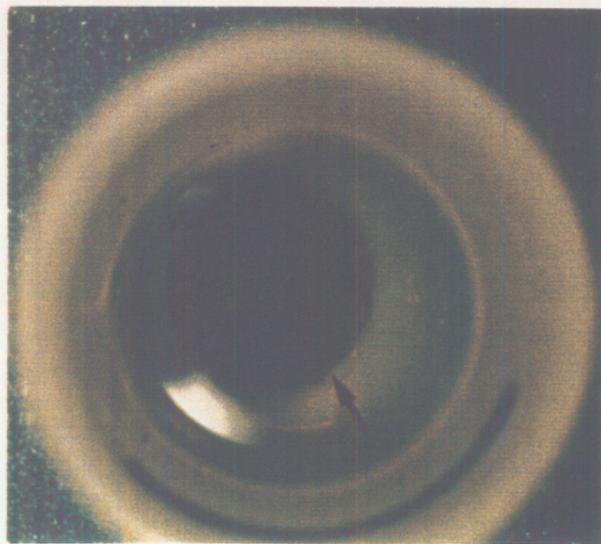


Figure 3. The needle-shaped precipitates on crack wall of concrete; (a) fresh concrete and (b) concrete exposed to deicing salts at fields.



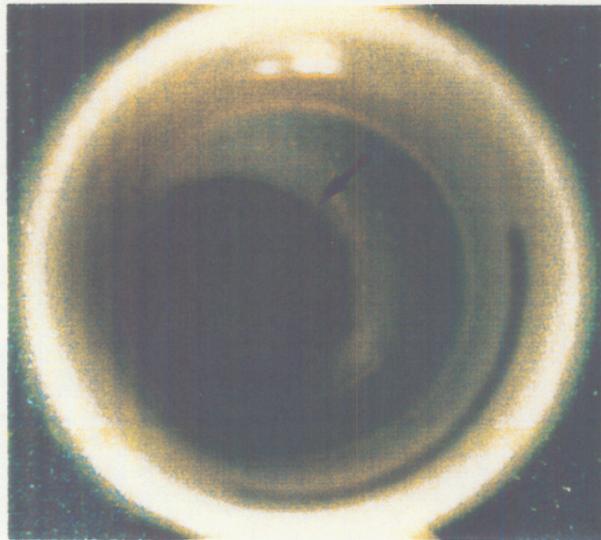
**2 DAYS**



polyethylene jar

cone-shaped concrete samples

**7 DAYS**



**70 DAYS**

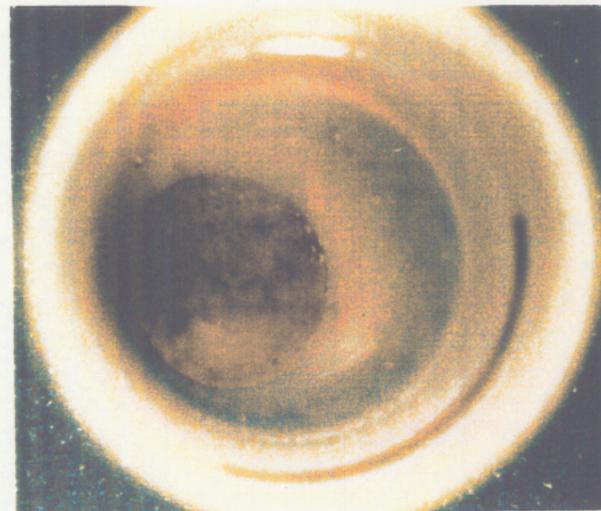
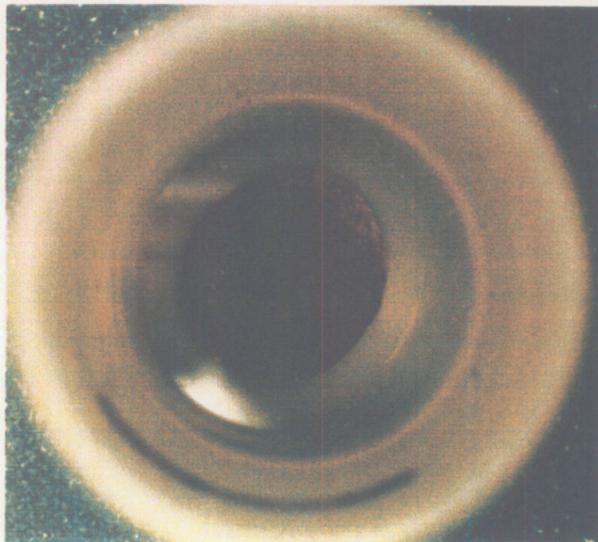


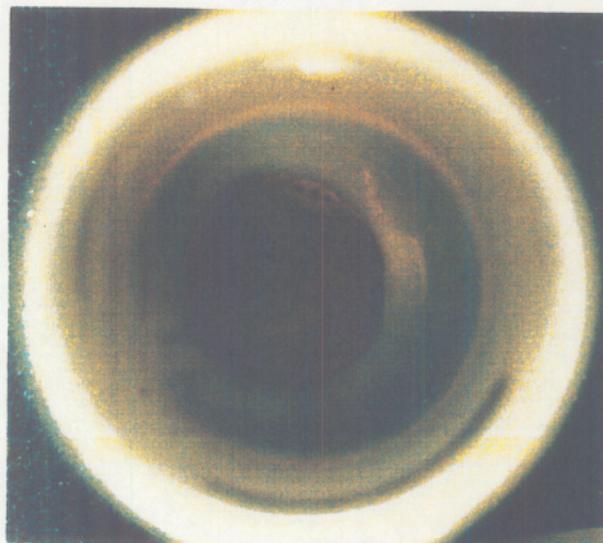
Figure 4. Top views of the test cells containing deionized water. No precipitate was found after 70 days.



**2 DAYS**



**7 DAYS**



**70 DAYS**

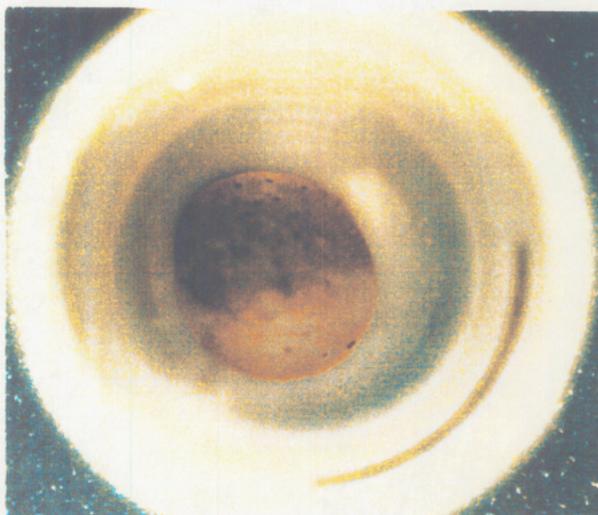


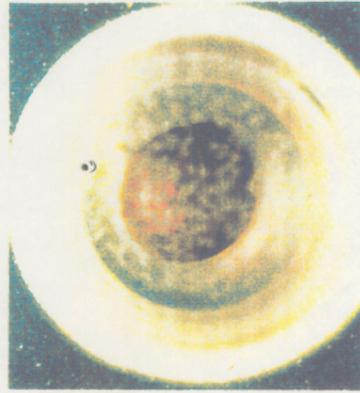
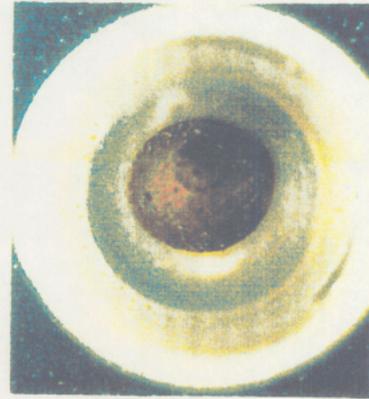
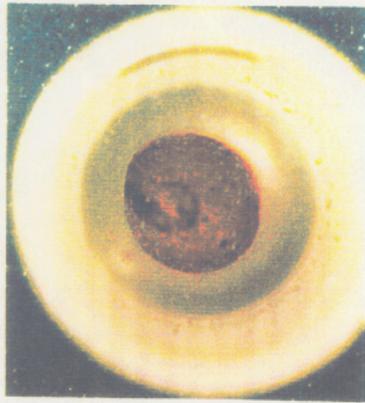
Figure 5. Top views of the test cells containing city water. No precipitate was found after 70 days.



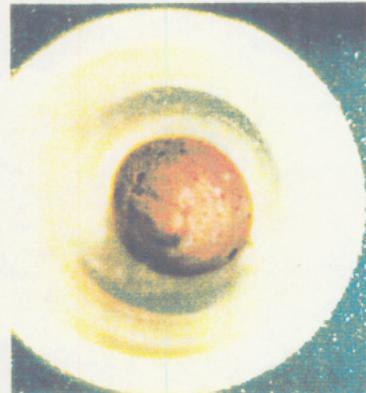
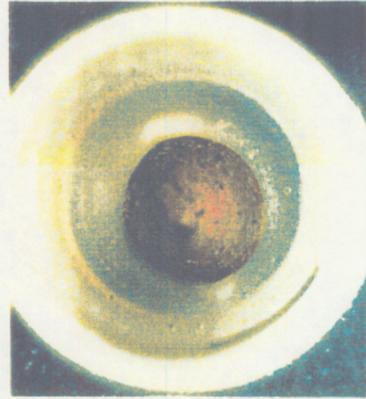
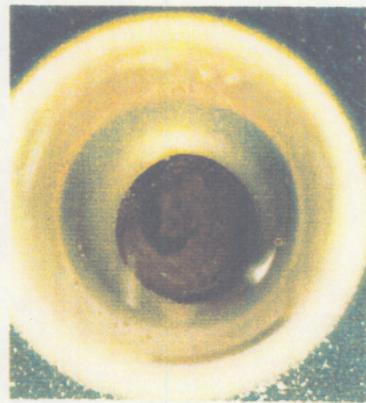
2 DAYS

7 DAYS

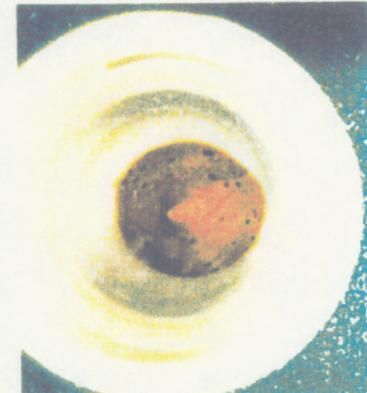
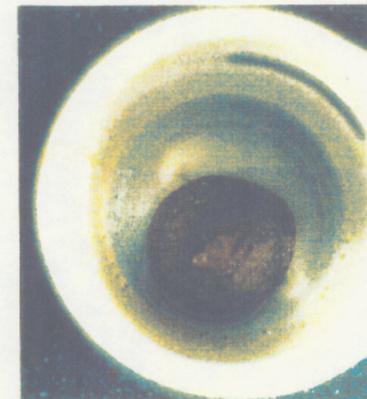
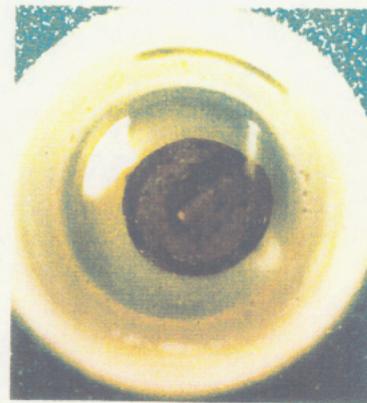
70 DAYS



3%



6%



20%

Figure 6. Top views of the test cells containing 3, 6 and 20% NaCl. No precipitate was found after 70 days.



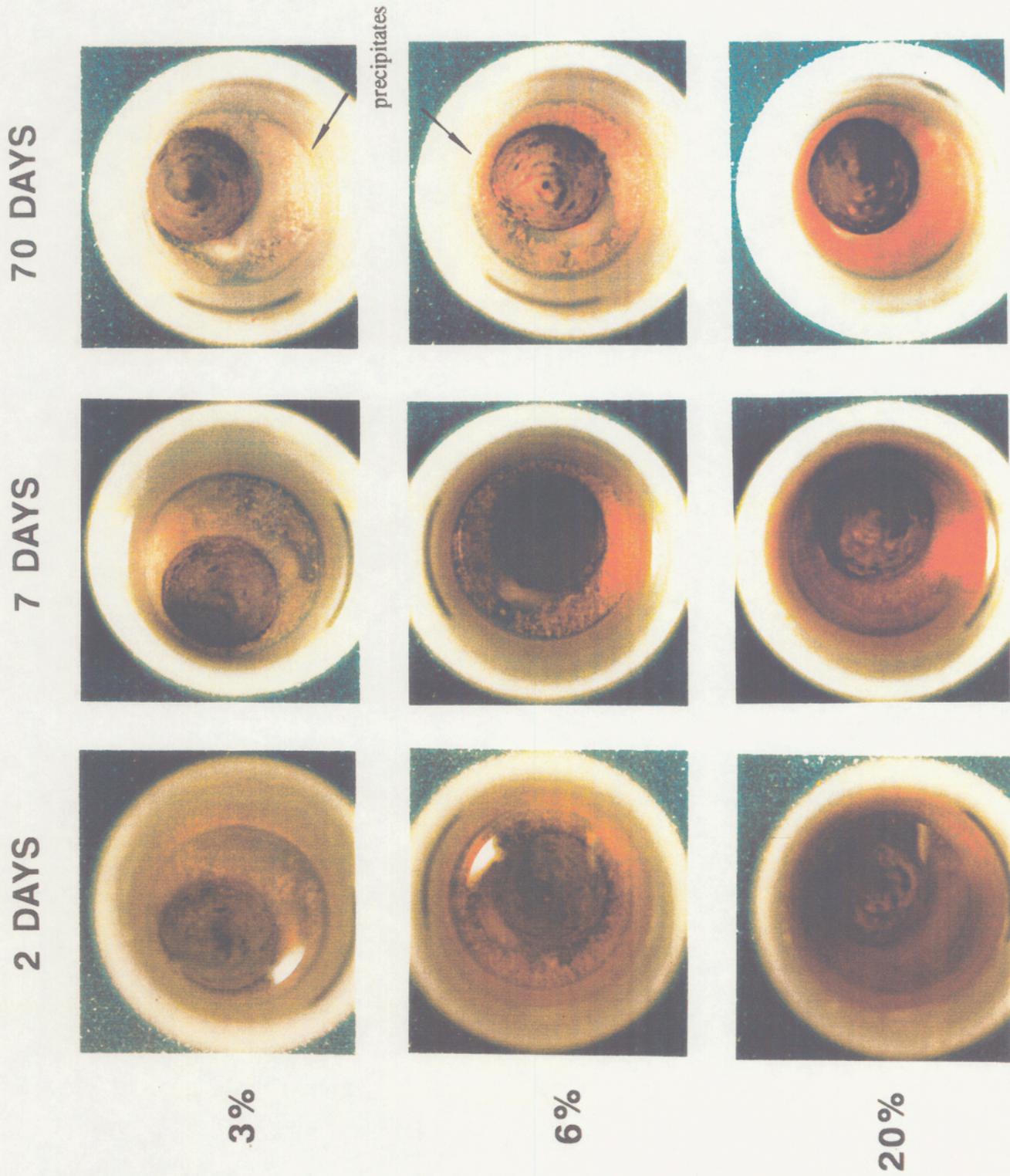


Figure 7. Top views of the test cells containing 3, 6 and 20% corrosion-inhibited Deicing Salt A. Precipitates increased with increased concentration, and as a function of time.



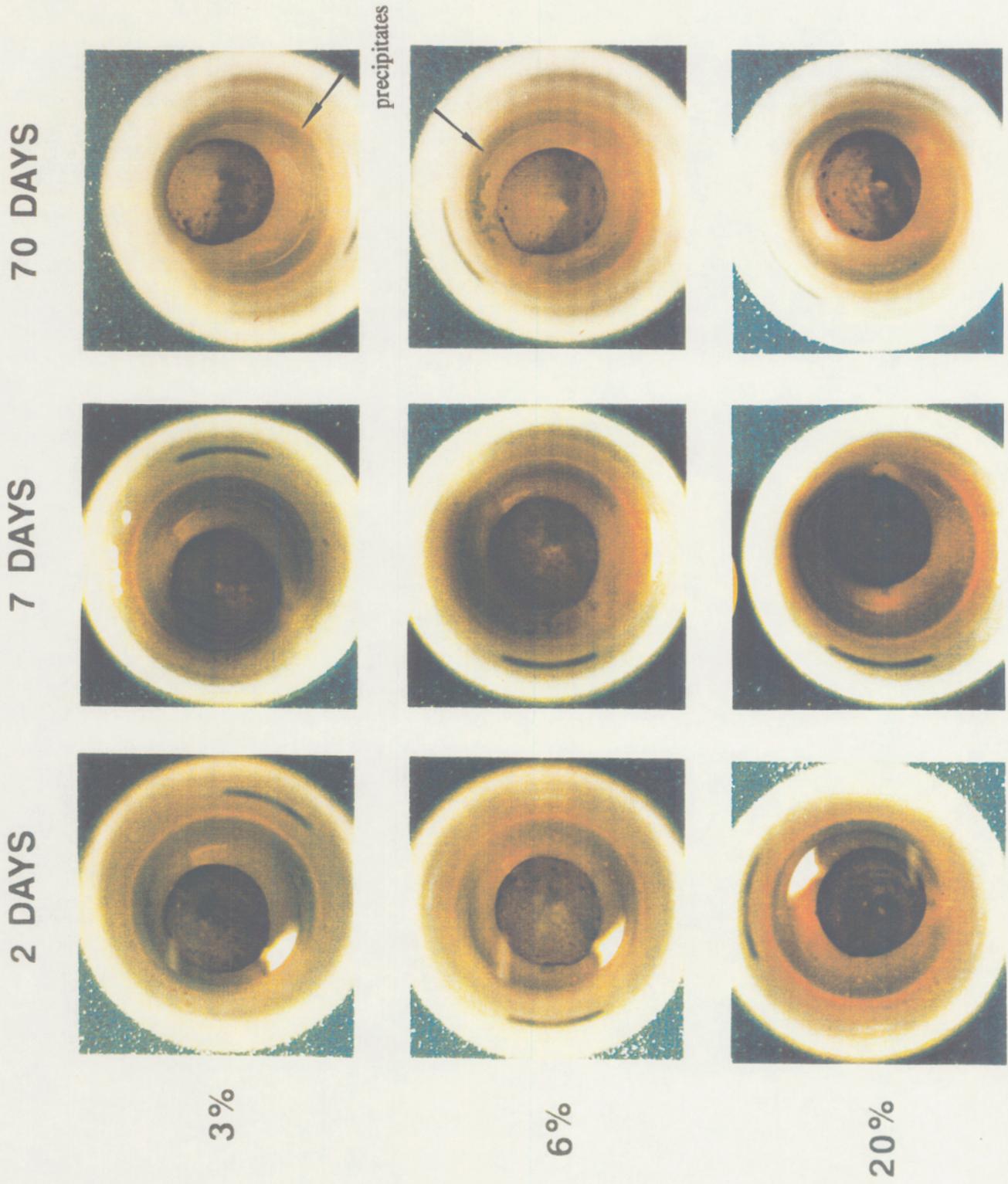


Figure 8. Top views of the test cells containing 3, 6 and 20% corrosion-inhibited Deicing Salt B. Small amount of precipitates was found after 70 days, but the color of test solutions changed from clear to yellowish.



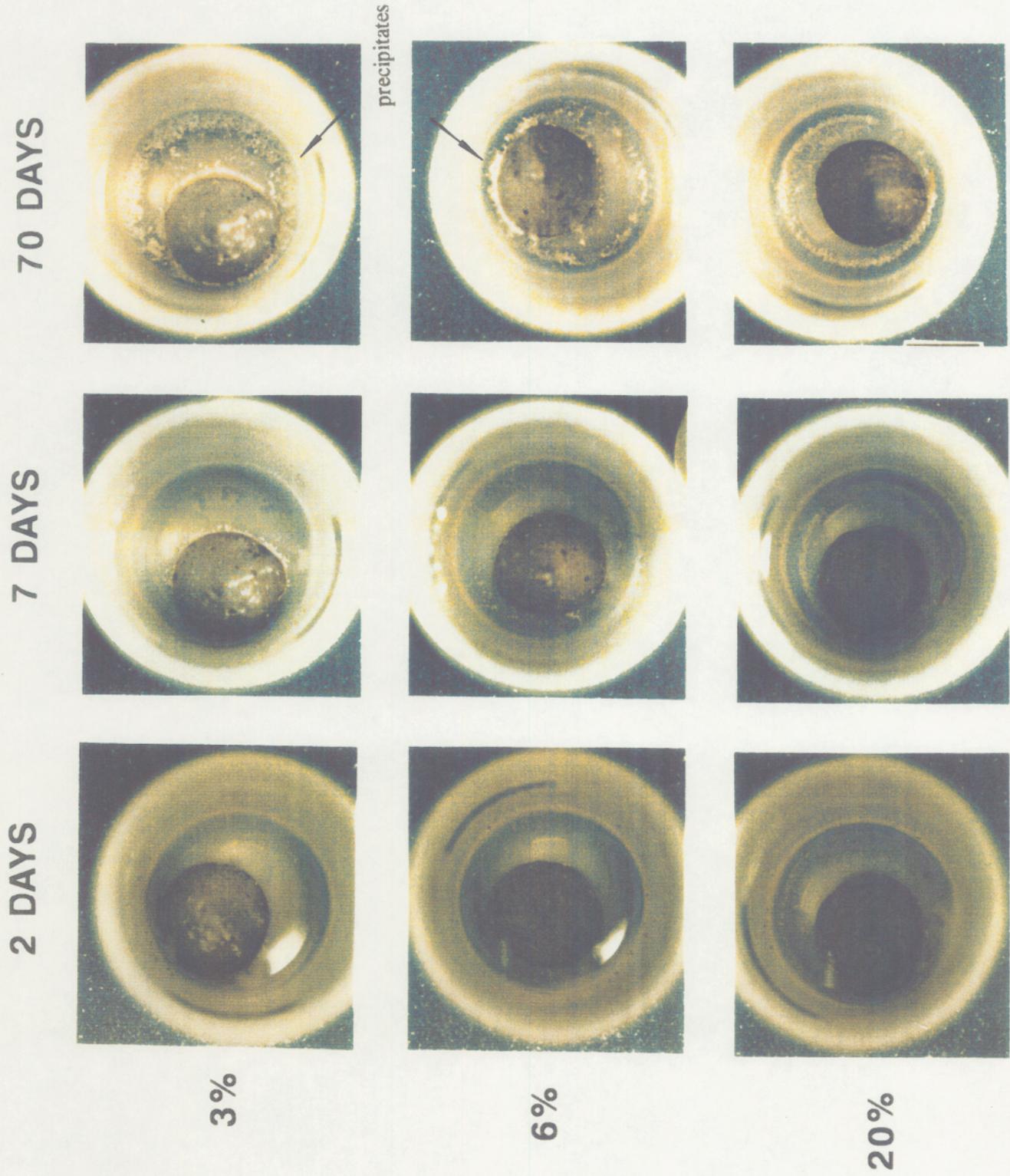


Figure 9. Top views of the test cells containing 3, 6 and 20% corrosion-inhibited Deicing Salt D. Precipitates increased with increased concentrator, and as a function of time.



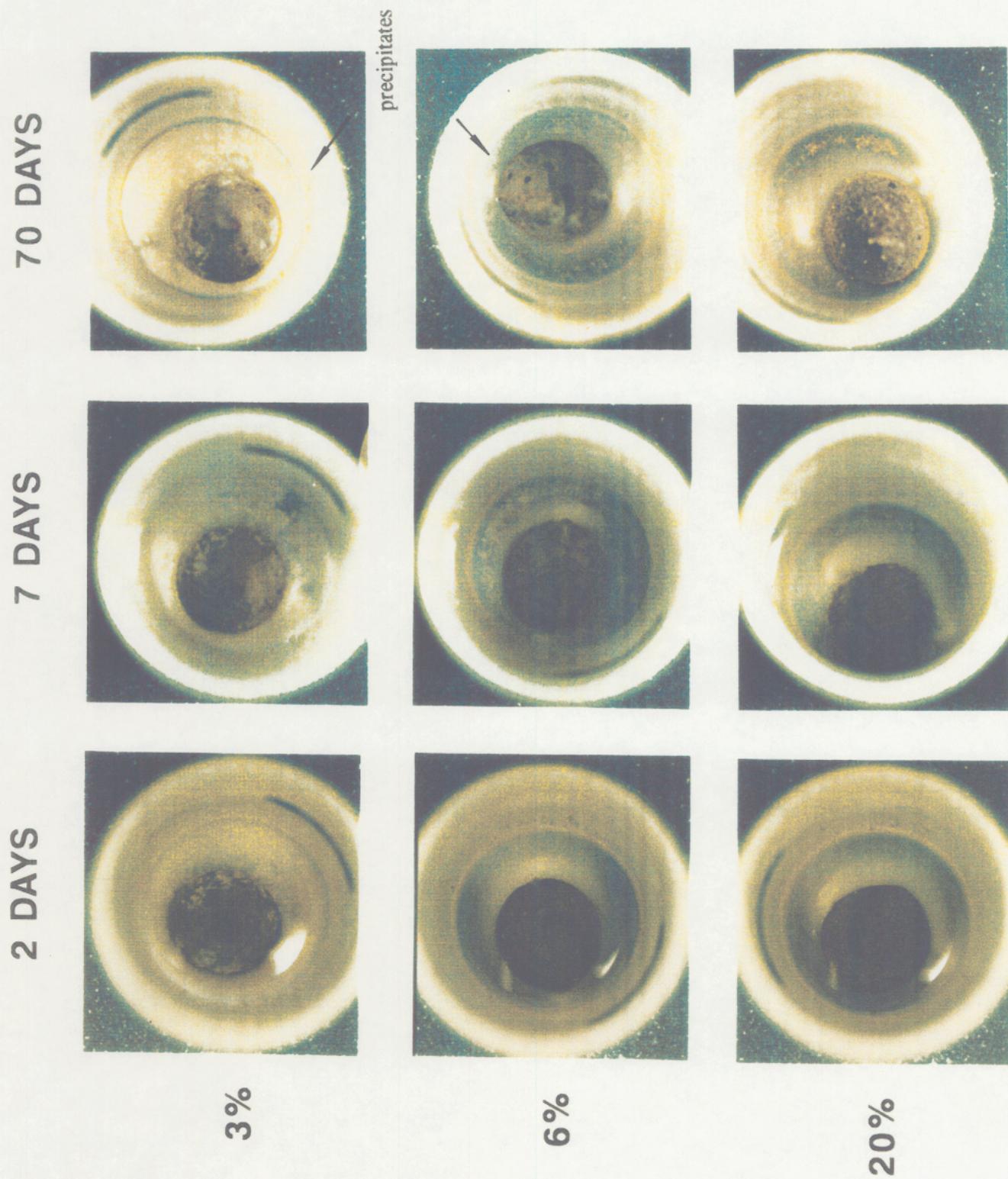


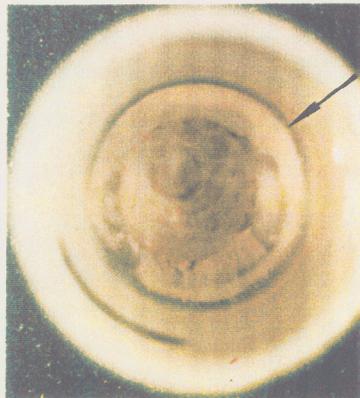
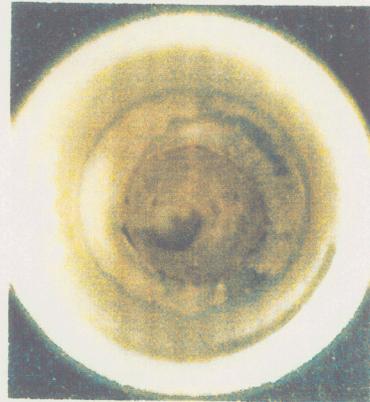
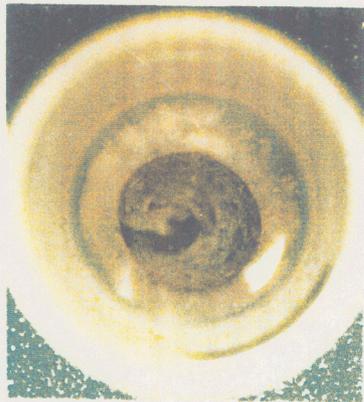
Figure 10. Top views of the test cells containing 3, 6 and 20% corrosion-inhibited Deicing Salt E. Precipitates decreased with increased concentration, but increased as a function of time.



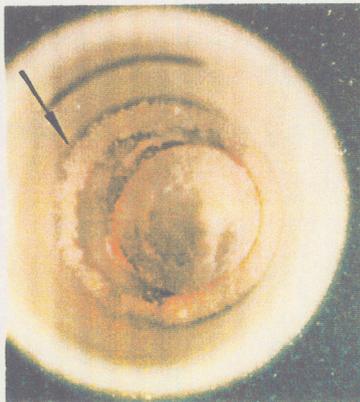
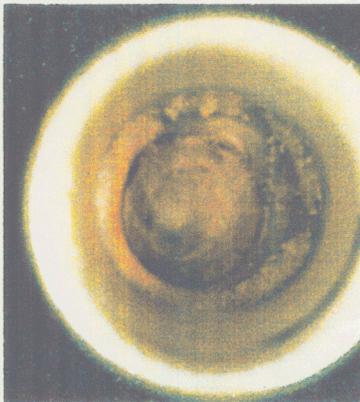
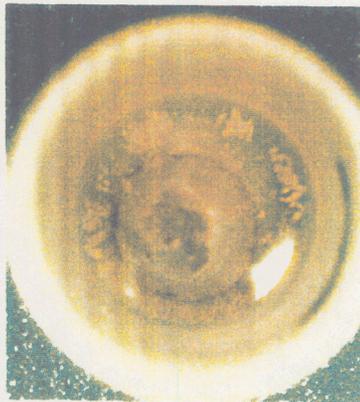
2 DAYS

7 DAYS

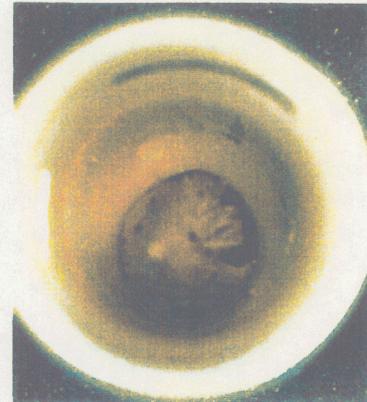
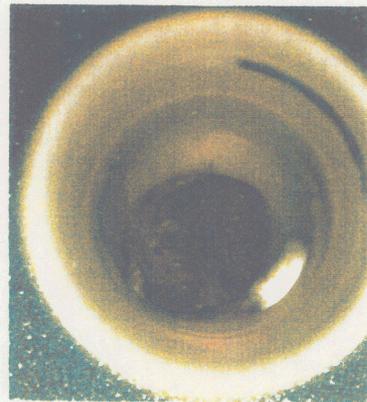
70 DAYS



3%



6%



20%

Figure 11. Top views of the test cells containing 3, 6 and 20% corrosion-inhibited Deicing Salt F. Precipitates decreased with increased concentration, but increased as a function of time.



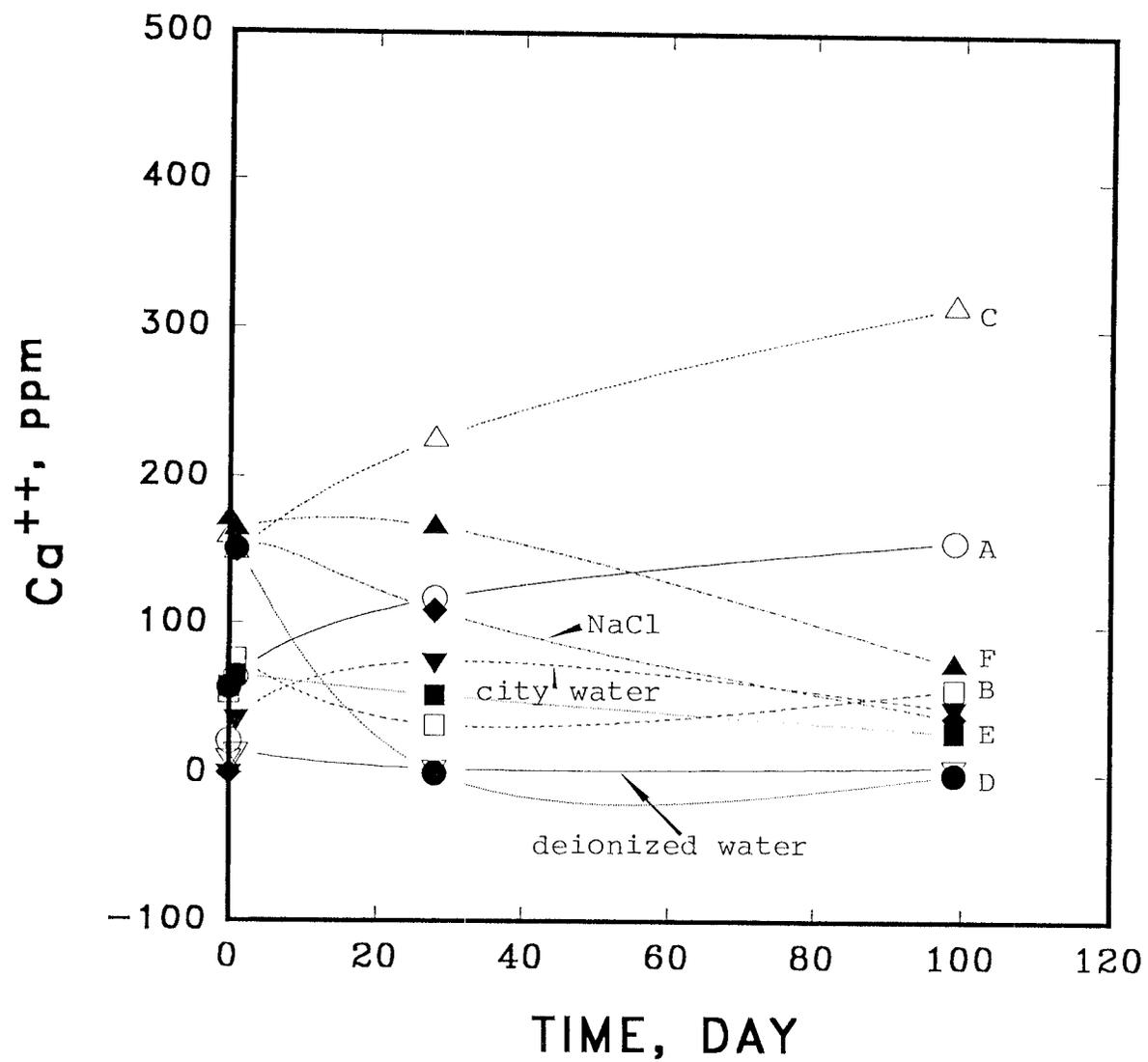


Figure 12.  $Ca^{++}$  changes in 3% corrosion-inhibited deicing salt solutions as a function of time.



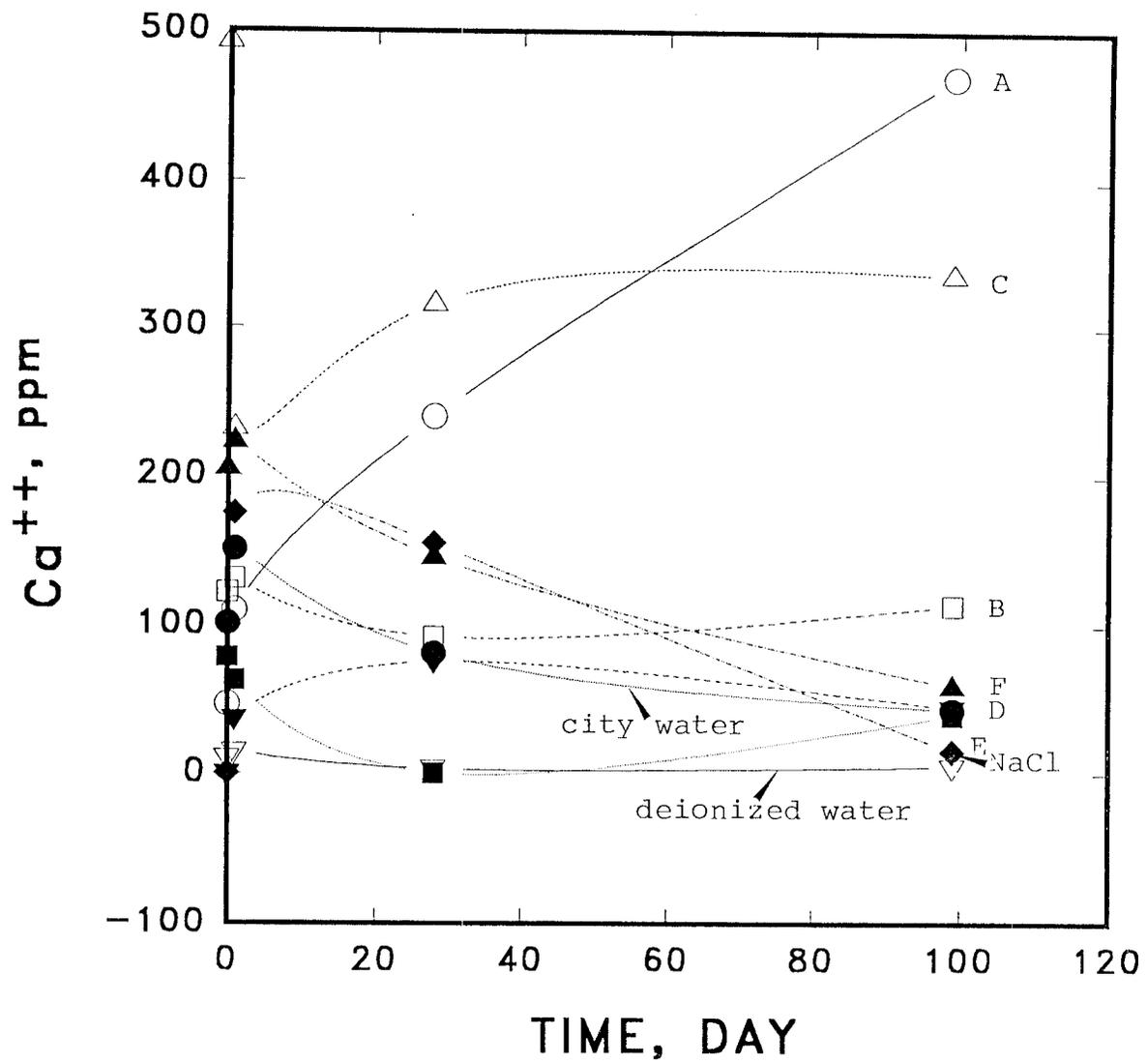


Figure 13. Ca<sup>++</sup> changes in 6% corrosion-inhibited deicing salt solutions as a function of time.



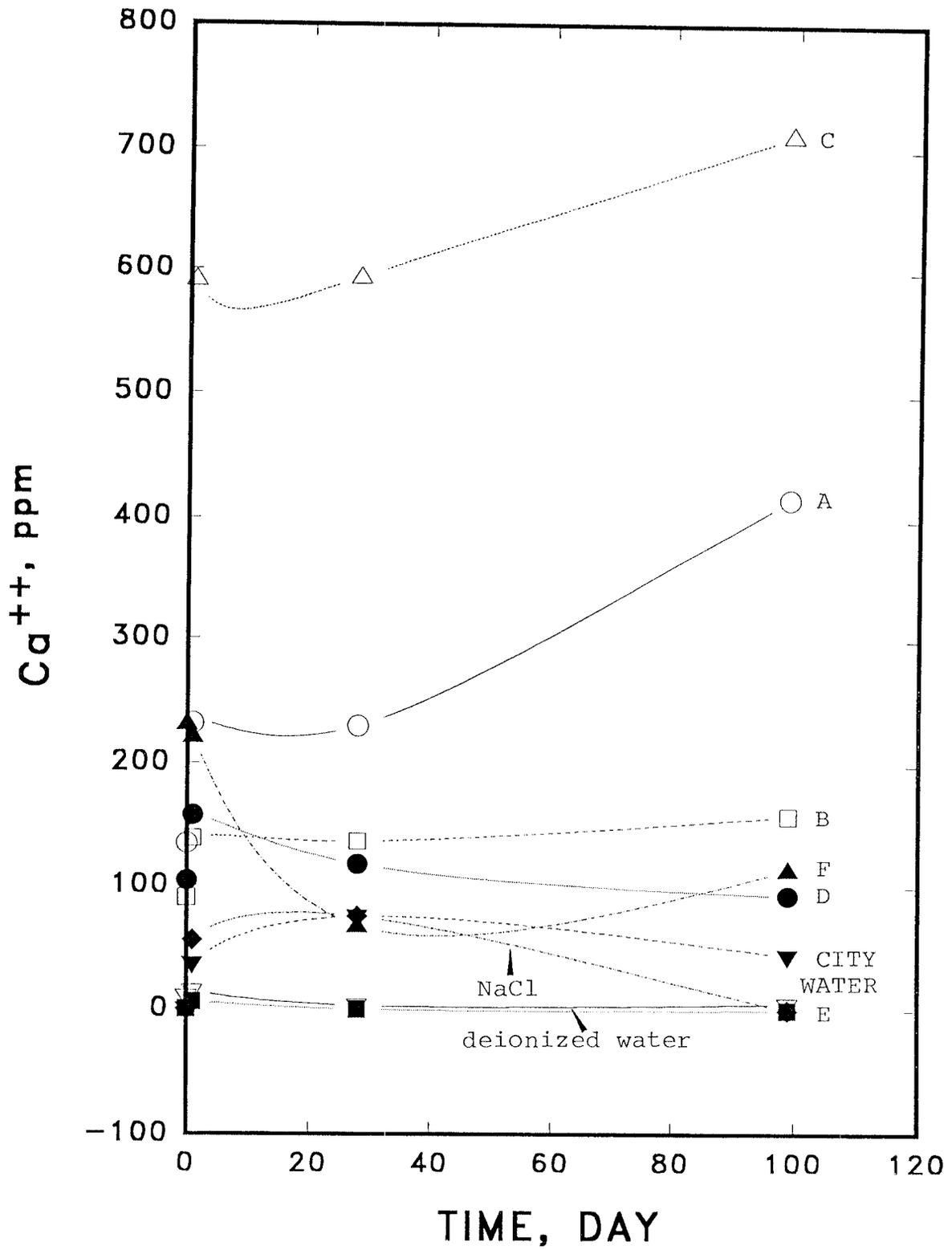


Figure 14.  $\text{Ca}^{++}$  changes in 20% corrosion-inhibited deicing salt solutions as a function of time.



#### 4. CONCLUSION

The results collected to date provide clear evidence of chemical reactions between concrete and the corrosion-inhibited deicing salts. The different amounts of precipitates (chemical reaction products) found in the test cells were dependant on the type and the concentration of corrosion-inhibited deicing salts. However, further research is necessary to complete the investigation of concrete degradation by the corrosion-inhibited deicing salts.

The cone-shaped concrete sample is expected to show the significant physical changes of the concrete by the corrosion-inhibited deicing salts. The precipitates should be collected from the test cells for quantitative and qualitative analysis to identify the degree of chemical reactions and the chemical elements involved in the reactions. The volume changes of the precipitates when dried can determine the impact of the precipitates on micro-cracks inside of concrete. The chemical changes in the solutions will provide the information about the changes of bonding-strength of concrete.



## Product Identification

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