# REDUCING CORROSION OF REINFORCING STEEL IN CONCRETE BRIDGE DECKS

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ABSTRACT

The corrosion of reinforcing in concrete bridge decks and other structural members containing chloride ion (from deicing salts) results in the cracking and spalling of the surface concrete, and the eventual destruction of the concrete.

In this study, concrete block specimens, containing reinforcing steel, were exposed in the laboratory to solutions of 5% NaCl in water containing various other salts to determine if any corrosion inhibiting action could be detected. The salts investigated were calcium hydroxide, sodium carbonate, sodium silicate and calcium nitrate.

Calcium hydroxide (hydrated lime) solutions showed little inhibiting effect; 1% sodium carbonate solutions tended to increase the rate of corrosion; 10% sodium carbonate showed some inhibiting effect but is probably not practical because of its caustic nature, and the sodium silicate and calcium nitrite solutions showed results that justify further study and field testing.

DISCLAIMER

The findings, opinions, conclusions and recommendations contained in this reort are those of the author and do not necessarily reflect official policies of the Idaho Transportation Department.

ACKNOWLEDGEMENTS

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# INTRODUCTION

The corrosion of reinforcng steel in concrete bridge decks and other members containing chloride ion results in the cracking and spalling of the surface concrete, and the eventual destruction of the structure.

It is generally agreed that chloride concentrations of more than 2.0 pounds per cubic yard of concrete (expressed as NaCl) is the lower limit at which corrosion may start to become a problem.

At concentrations greater than 2.0 pound per cubic yard, the natural protection of the steel by the relatively high pH of the surrounding concrete begins to be lost and the steel, in the presence of $O_2$ and water, may start to corrode. The corrosion is in the form of oxydation products of iron, which have a greater volume than the original reinforcing steel.

The pressures from this increasing volume eventually exceed the strength of the concrete which then cracks and spalls.

It has been observed that if a high pH ( 12.0) can be maintained around the steel, the corrosion is inhibited.

It has also been observed that half-cell potential voltages are an indication of the rate of corrosion of steel in concrete so these potentials were monitored during the course of the tests.

In this project, the following activities were undertaken:

1. To study methods of maintaining a high pH around the steel in bridge decks by the addition of strong alkaline materials to bridge decks as spray-on solutions or to the deicing materials used on bridge decks. The alkaline materials investigated included hydrated

lime ($Ca(OH)_2$), sodium carbonate ($Na_2CO_3$) and sodium silicate ($Na_2SiO_3$ or $Na_2Ox$ X $SiO_2$) in various concentrations.

2. Study the inhibiting effect of the addition of calcium nitrite ($Ca(NO_2)_2$) to concrete mixes and to deicing salts.

## OUTLINE OF TESTING PROGRAM

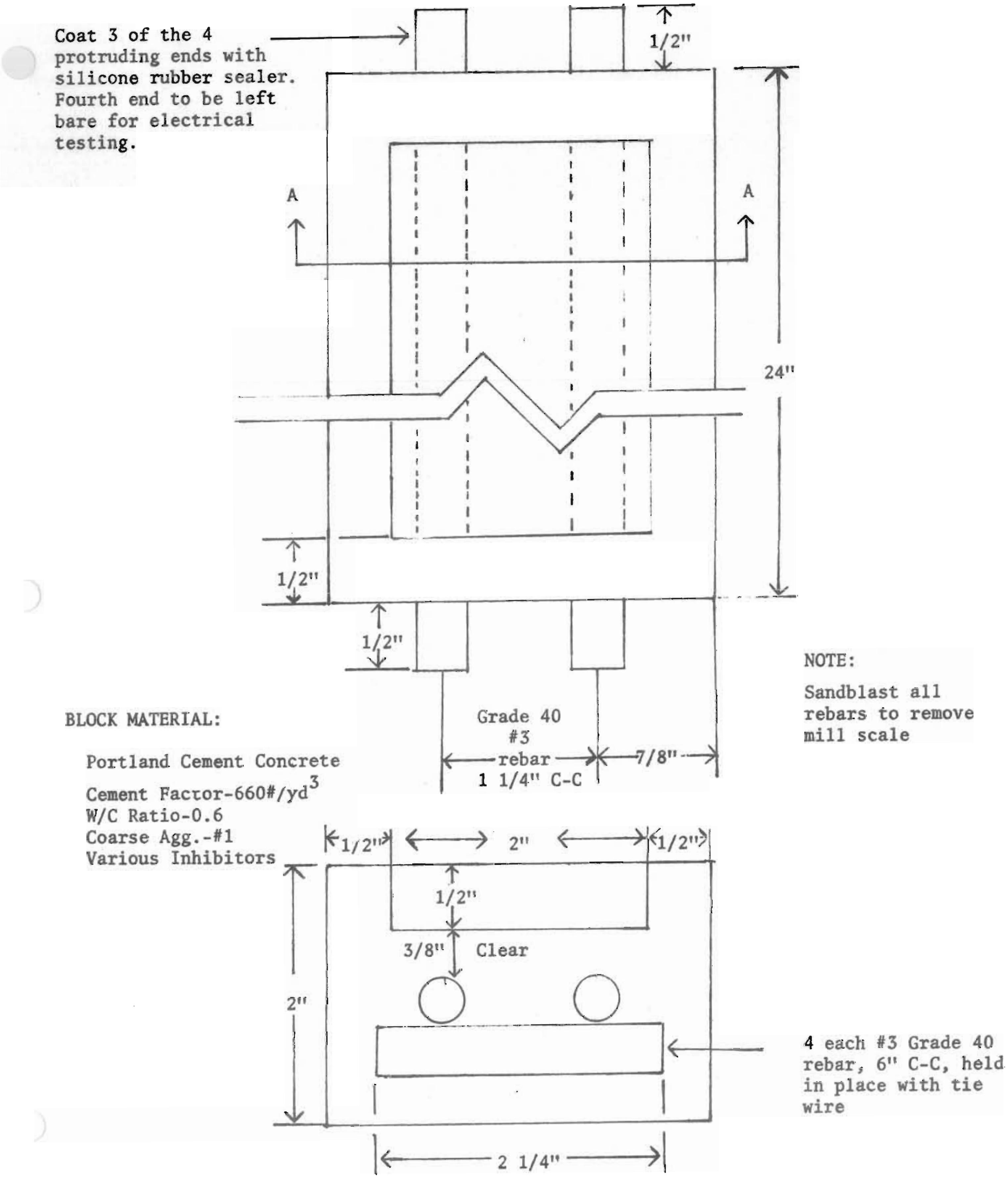
Eighteen concrete blocks containing reinforcing steel were made (see following sketch). All blocks were made with 1/2-inch maximum coarse aggregate, Type II cement (six bags), 0.6 water-cement ratio with approximately seven inch slump. All blocks were wet-cured 14 days, then air-dried for 14 days before testing.

The reinforcing steel was Grade 40, Size 3, sand-blasted to white metal and weighed before being cast into the blocks. Block Numbers 15, 16, 17 and 18 were cast with 2.5 percent $Ca(NO_2)_2$ by weight of cement, added during the mixing.

After curing, the test blocks were subjected to alternate weeks of exposure of salt solution (at room temperature) and oven drying (115$^{O}$F). The solutions were ponded in 1/2-inch deep recesses on top of the test blocks and replenished as necessary to avoid complete evaporation. The solutions were drained before oven drying.

As salt encrustation tended to build up on the surfaces of the blocks after the first few wet-dry cycles, the blocks were lightly washed with fresh water and surface dried with a towel before oven drying. At the end of the tests, the blocks were broken up, the steel recovered, cleaned and reweighed to determine weight loss.

# SKETCH I




Test Block for Corrosion Inhibitor Evaluation

Half-cell electrical potentials were recorded at the end of each salt exposure cycle. Development of cracks and/or rust stain were noted.

The test blocks were numbered 1 through 18. The tests blocks were exposed as follows:

| Block Number | Exposure Solution |
|---|---|
| 1, 2 | 5% NaCl Solution + 0.1% $Ca(OH)_2$ |
| 3, 4 | 5% NaCl in saturated ($Ca(OH)_2$) Solution + 3% $Ca(NO_2)_2$ |
| 5, 6 | 5% NaCl in saturated ($Ca(OH)_2$) Solution |
| 7 | 5% NaCl + 1% Sodium Carbonate |
| 8 | 5% NaCl + 1% Sodium Silicate |
| 9 | 5% NaCl + 5% Sodium Silicate |
| 10 | 5% NaCl + 10% Sodium Silicate |
| 11 | 5% NaCl + 5% $Na_2CO_3$ |
| 12, 13, 14, | 5% NaCl + 5% NaCl |
| 15, 16 | 5% NaCl (Blocks made with 2½% $Ca(NO_2)_2$ by wt. of cement) |
| 17, 18 | 5% NaCl + 3% $Ca(NO_2)_2$ with 2½% $Ca(NO_2)_2$ by wt. of cement) |

Exposure to the solutions on block numbers 1 and 2 were started December 19, 1977; 5 through 14 were started on December 21, 1977 and block numbers 15 through 18 on January 16, 1978. When a block deteriorated to the point where it would no longer hold the solutions, it was removed from the tests. For example, block numbers 1, 3, 5, and 13 were removed on June 19, 1978. By October 24, 1978, when the tests were stopped, only block numbers 3, 4, 8, 9, 10, 11, 15, 16, 17, and 18 were still holding solutions.

The following are half-cell (Ag-AgCl) readings taken at the end of the wet cycle. Figures shown are negative millivolts. To convert Ag-AgCl to $Cu/CuSO_4$, add -74 millivolts.

Negative Millivolts | TABLE I | Ag-AgCl | Pa[illegible] 8

| DATES | BLOC[illegible] NUMBERS | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1st Read | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | Cycle |
| 11/21/77 | ---- | ---- | 125 | 125 | 125 | 125 | 150 | 125 | 125 | 110 | 95 | 150 | 125 | 125 | ---- | ---- | ---- | ---- | Dry |
| 11/28/77 | ---- | ---- | 164 | 135 | 334 | 315 | 300 | 380 | 320 | 245 | 300 | 355 | 353 | 328 | ---- | ---- | ---- | ---- | Wet |
| 12/05/77 | ---- | ---- | 85 | 115 | 235 | 190 | 155 | 265 | 185 | 235 | 130 | 195 | 240 | 260 | ---- | ---- | ---- | ---- | Dry |
| 12/12/77 | ---- | ---- | 245 | 155 | 370 | 355 | 410 | 440 | 375 | 380 | 405 | 485 | 515 | 385 | ---- | ---- | ---- | ---- | Wet |
| 12/19/77 | 165 | 175 | 315 | 275 | 380 | 380 | 420 | 440 | 380 | 375 | 445 | 410 | 460 | 450 | ---- | ---- | ---- | ---- | Dry |
| 12/27/77 | 385 | 455 | 395 | 385 | 735 | 730 | 705 | 645 | 505 | 465 | 515 | 615 | 530 | 510 | ---- | ---- | ---- | ---- | Wet |
| 01/03/78 | 335 | 345 | 380 | 320 | 435 | 420 | 475 | 455 | 305 | 275 | 465 | 450 | 475 | 420 | ---- | ---- | ---- | ---- | Dry |
| 01/09/78 | 635 | 620 | 330 | 320 | 640 | 645 | 645 | 660 | 390 | 310 | 480 | 845 | 635 | 595 | ---- | ---- | ---- | ---- | Wet |
| 01/16/78 | 335 | 300 | 320 | 255 | 635 | 340 | 765 | 350 | * | * | 340 | 340 | 325 | 400 | 120 | 115 | 115 | 80 | Dry |
| 01/23/78 | 435 | 470 | 335 | 310 | 630 | 645 | 665 | 505 | 265 | 190 | 475 | 480 | 525 | 485 | 135 | 240 | 130 | 130 | Wet |
| 01/30/78 | 815 | 385 | 345 | 200 | 735 | 720 | 795 | 335 | 375 | 75 | 385 | 375 | 380 | 430 | 125 | 130 | 135 | 135 | Dry |
| 02/06/78 | 620 | 500 | 390 | 415 | 645 | 660 | 660 | 490 | 225 | 200 | 530 | 765 | 675 | 650 | 525 | 480 | 145 | 95 | Wet |
| 02/13/78 | 430 | 440 | 565 | 370 | 410 | 440 | 435 | 390 | * | * | 400 | 410 | 390 | 450 | 195 | 185 | 110 | 160 | Dry |
| 02/21/78 | 675 | 665 | 410 | 405 | 655 | 695 | 640 | 500 | 125 | 150 | 525 | 650 | 680 | 630 | 535 | 500 | 295 | 210 | Wet |
| 02/27/78 | 480 | 430 | 585 | 370 | 430 | 440 | 415 | * | * | * | 385 | 420 | 390 | 415 | 200 | 205 | 105 | 105 | Dry |
| 03/06/78 | 645 | 650 | 600 | 400 | 655 | 700 | 680 | 590 | 150 | 170 | 540 | 640 | 675 | 645 | 420 | 495 | 305 | 180 | Wet |
| 03/13/78 | 480 | 405 | 520 | 380 | 425 | 450 | 440 | 390 | * | * | 410 | 425 | 395 | 410 | 255 | 300 | 200 | 195 | Dry |
| 03/20/78 | 500 | 600 | 330 | 325 | 670 | 675 | 660 | 555 | 160 | 185 | 565 | 625 | 570 | 640 | 435 | 730 | 305 | 285 | Wet |
| 03/27/78 | 460 | 420 | 295 | 365 | 415 | 425 | 400 | 390 | * | * | 400 | 425 | 410 | 450 | 295 | 265 | 175 | 155 | Dry |
| 04/03/78 | 630 | 645 | 755 | 355 | 660 | 660 | 645 | 585 | 370 | 170 | 525 | 530 | 645 | 755 | 540 | 565 | 295 | 225 | Wet |
| 04/10/78 | 445 | 390 | 325 | 345 | 405 | 435 | 410 | 375 | * | * | 400 | 410 | 400 | 395 | 280 | 305 | 160 | 140 | Dry |
| 04/17/78 | 625 | 655 | 555 | 345 | 655 | 665 | 640 | 610 | 220 | 175 | 520 | 630 | 635 | 635 | 500 | 565 | 320 | 270 | Wet |
| 04/24/78 | 395 | 360 | 300 | 190 | 730 | 385 | 350 | 365 | * | * | 390 | 395 | 315 | 370 | 300 | 295 | 180 | 150 | Dry |
| 05/01/78 | 460 | 465 | 315 | 285 | 715 | 670 | 645 | 605 | 135 | 150 | 620 | 630 | 625 | 635 | 505 | 575 | 405 | 370 | Wet |
| 05/07/78 | 385 | 345 | 305 | 340 | 390 | 390 | 400 | 380 | * | * | 400 | 385 | 340 | 360 | 330 | 310 | 450 | 215 | Dry |
| 05/22/78 | 615 | 640 | 480 | 475 | 655 | 670 | 670 | 635 | 290 | 480 | 625 | 625 | 635 | 645 | 630 | 565 | 430 | 470 | Wet |
| 06/01/78 | 300 | 210 | 220 | 285 | 230 | 300 | 530 | 285 | * | 330 | 355 | 350 | 170 | 255 | 230 | 205 | 160 | 215 | Dry |
| 06/07/78 | 595 | 600 | 395 | 500 | 630 | 635 | 625 | 400 | 210 | 360 | 610 | 615 | 600 | 590 | 515 | 530 | 420 | 630 | Wet |
| 06/13/78 | 400 | 330 | 230 | 290 | 365 | 385 | 380 | 200 | * | * | 425 | 405 | 395 | 350 | 295 | 320 | 250 | 250 | Dry |
| 06/19/78 | X | 430 | 275 | 430 | X | 635 | X | 425 | 220 | 355 | 600 | 625 | X | 605 | 745 | 570 | 715 | 680 | Wet |
| 06/27/78 | | 235 | 435 | 340 | | 310 | | * | 195 | * | 390 | 360 | | 300 | 280 | 315 | 200 | 220 | Dry |
| 07/05/78 | | 530 | 255 | 420 | | 625 | | 455 | 370 | 230 | 620 | 500 | | 515 | 595 | 575 | 390 | 390 | Wet |
| 07/10/78 | | 350 | 320 | 360 | | 370 | | 300 | * | * | 425 | 455 | | 405 | 370 | 350 | 250 | 240 | Dry |
| 07/17/78 | | 550 | 450 | 470 | | 635 | | 530 | 210 | 460 | 625 | 630 | | 615 | 600 | 580 | 465 | 420 | Wet |
| 07/24/78 | | X | 300 | 210 | | X | | 300 | * | * | 350 | 370 | | 335 | 280 | 260 | 230 | 175 | Dry |
| 07/31/78 | | | 365 | 310 | | | | 600 | 195 | 450 | 605 | 620 | | 615 | 665 | 575 | 440 | 520 | Wet |
| 08/07/78 | | | 400 | 320 | | | | 300 | * | * | 390 | 380 | | 345 | 325 | 315 | 245 | 340 | Dry |
| 08/13/78 | | | 360 | 395 | | | | 565 | 175 | 565 | 595 | 615 | | 610 | 590 | 575 | 520 | 240 | Wet |
| 08/21/78 | | | 290 | 295 | | | | 240 | * | * | 285 | 350 | | 325 | 300 | * | * | * | Dry |
| 08/28/78 | | | 340 | 405 | | | | 460 | 140 | 515 | 570 | 605 | | 600 | 590 | 555 | 305 | 515 | Wet |
| 09/05/78 | | | 250 | 210 | | | | * | * | * | 340 | 340 | | 310 | 295 | 350 | 150 | 440 | Dry |
| 09/11/78 | | | 325 | 400 | | | | 340 | 135 | 525 | 500 | X | | X | 570 | 580 | 380 | 260 | Wet |
| 09/25/78 | | | 380 | 380 | | | | 310 | 170 | 555 | 530 | | | | 580 | 575 | 375 | 390 | Wet |
| 10/02/78 | | | 300 | 325 | | | | * | * | * | 320 | | | | 340 | 330 | 150 | 210 | Dry |
| 10/17/78 | | | 345 | 450 | | | | 365 | 245 | 505 | 600 | | | | 450 | 445 | 310 | 205 | Wet |
| 10/24/78 | | | 280 | 230 | | | | -55 | -100 | * | 410 | | | | 335 | 310 | 220 | 170 | Dry |

## DISCUSSION

Block Numbers 1 and 2 ($5\%$ NaCl + $0.1\%$ $Ca(OH)_2$)

Tests were started on December 19, 1977. By April 24, 1978, the blocks showed some rust spots and slight cracking. On June 19, 1978, block number 1 no longer held solution overnight and was removed from the tests. On July 17, 1978, block number 2 no longer held solution and was removed from the tests.

CONCLUSIONS:

The 0.1% $Ca(OH)_2$) in the 5% salt solution was not effective in reducing corrosion. Metal loss was 3.1%.

Block Numbers 3 and 4 ($5\%$ NaCl + $3\%$ $Ca(NO_2)_2$)

Tests started November 21, 1977. At the end of testing, a slight leak had developed in block number 4 with some rust discoloration. No cracking was observed. The surface of the blocks showed a slight weathered appearance, possibly due to the wet and dry cycles. Metal loss was 4.4%.

CONCLUSIONS:

Observed test results show the addition of 3% $Ca(NO)_2$ to the test solution did not reduce corrosion.

Block Numbers 5 and 6 ($5\%$ NaCl + Sat $Ca(OH)_2$)

On June 19, 1977, block number 5 no longer held solution and on July 24, 1977, block 6 no longer held solution.

CONCLUSIONS:

As in block numbers 1 and 2, the addition of saturated $Ca(OH)_2$ to the 5% NaCl solution was not effective in reducing corrosion. Metal loss was 3.0% and 3.7%.

Block Number 7 ($5\%$ NaCl + $1\%$ $Na_2CO_3$)

Block number 7 failed to hold test solution by June 7, 1977 and tests were discontinued.

CONCLUSIONS:

The 1% $Na_2CO_3$ was not effective in reducing corrosion. Metal loss was 1.5%.

Block Numbers 8, 9, and 10 (5% NaCl+1%-5%-10% $NaSiO_3$)

These blocks went through the complete test from November 21, 1977 to October 17, 1978 without leaking. At the end of the test period, block number 8 showed two full length cracks over the long steel; block number 9 was in good condition with no cracks and block number 10 showed slight cracking.

CONCLUSIONS:

The 5% solution of sodium silicate appeared to have as beneficial effect on both the cracking and keeping the half-voltage lower than the other solutions. All of the solutions also showed a tendency to seal the surface and make it somewhat resistant to rewetting. Further study may be justified. Metal loss was 8.5%, 1.1% and 3.0% respectively.

Block Number 11 (5% NaCl + 5% $Na_2CO_3$)

Block number 11 completed the test with moderate cracking and no leaks.

CONCLUSIONS:

Metal loss was 4.0%. This was not considered effective for field use.

Block Numbers 12, 13 and 14 (5% NaCl only)

Block 13 was leaking by June 19 and removed from testing. Block numbers 12 and 14 were leaking and removed from testing on August 28, 1978.

CONCLUSIONS:

The metal loss was 5.7%, 3.8% and 6.3% respectively. These blocks were for comparison standards only.

Block Numbers 15 and 16 (5% NaCl solution)

These blocks were cast with 2.5% $Ca(NO_2)_2$ by weight of cement. At the end of the test period, these blocks showed some rust stains but no cracks.

CONCLUSIONS:

The metal loss was 2.2% and 2.1% respectively. Calcium nitrite additive reduced corrosion.

Block Numbers 17 and 18 (5% NaCl + 3% $Ca(NO_2)_2$

These blocks were cast with 2.5% $Ca(NO_2)_2$ by weight of cement. At the end of the test period, they showed no stains or cracks.

CONCLUSIONS:

Weight loss of the metal was 0.3% and 0.4%. Calcium nitrite additive reduced corrosion.

## RECOMMENDATIONS

With the small number of test specimens, the correlation of half-cell readings, metal weight loss and block appearance is not particularly obvious but taken together indicate that only the 5% sodium silicate and the $Ca(NO_2)_2$ added to the concrete mix show any promise.

The sodium silicate suffers one of the same disadvantage as lindseed oil, that is, it takes repeated applications to be effective. This leaves the calcium nitrite as a practical substance in this test series showing effectiveness in reducing steel corrosion in concrete.

It is not effective if only added to the deicing salt. It must be an additive to the concrete itself.

At this time, a supplier of calcium nitrite recommends 2% to 4% be added to fresh concrete. It would appear that the higher concentration (4%) would be more effective, if economically feasible.