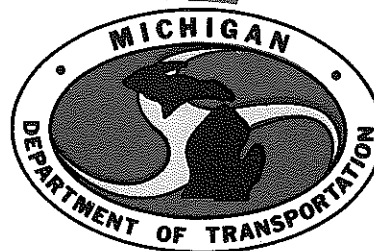


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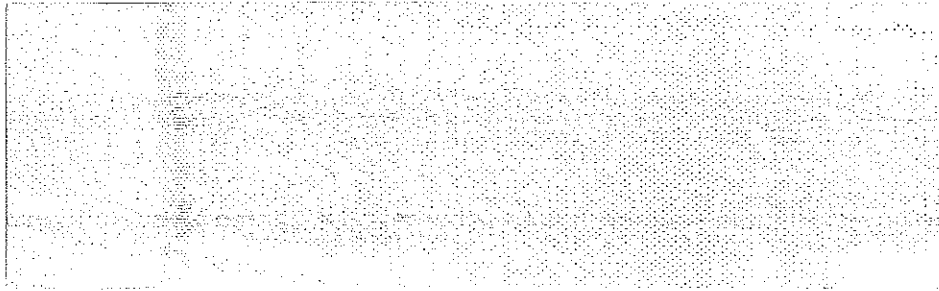
EVALUATION OF CALCIUM MAGNESIUM ACETATE (CMA)
AS A DEICING AGENT: CORROSION PHASE -
A COMPARATIVE EVALUATION OF THE EFFECTS OF
CMA VS. SALT (NaCl) ON HIGHWAY METALS
(3-MONTH EXPOSURE)



MATERIALS and TECHNOLOGY DIVISION



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TD870 .M33 c. 3
Evaluation of calcium
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R. L. McCrum
J. W. Reincke
J. W. Lay

Research Laboratory Section
Testing and Research Division
Research Project 82 G-259
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Michigan Transportation Commission
William C. Marshall, Chairman;
Lawrence C. Patrick, Jr., Vice-Chairman;
Hannes Meyers, Jr., Carl V. Pellonpaa,
Weston E. Vivian, Rodger D. Young
James P. Pitz, Director
Lansing, March 1985

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ABSTRACT

Calcium magnesium acetate (CMA) has been selected in FHWA sponsored research (Alternate Highway Deicing Chemicals - Report #FHWA-RD-79-108) as being among the most viable salt (NaCl) substitutes for highway deicing. While CMA has been reported to be less corrosive than NaCl the literature presently available sometimes has been inconsistent and has lacked the quantitative results necessary to properly evaluate the cost effectiveness of CMA usage.

This study documents the corrosiveness of a water solution of CMA as compared with that of an equivalent (for deicing purposes) concentration of NaCl in water, for identical exposure environments for the major structural metals currently used in Michigan's highway system.

For the weathering environment used, the CMA specimens experienced only one-third to one-tenth the average corrosion of the NaCl specimens with less severe pitting as well. Results are reported in detail for structural (bridge) steels, steel bar reinforcement for concrete, steel prestressing strand for concrete, some aluminum alloys, galvanizing, and some galvanic couples as well as a few other materials.

INTRODUCTION AND OVERVIEW

Sodium chloride (NaCl), due to its geologic abundance, has long been a cheap and readily available highway deicing agent. Unfortunately, NaCl contributes significantly to the corrosion of almost all metals in a highway environment and can produce deleterious environmental effects. The damage done by NaCl has been estimated as being 20 times its initial cost (1).

The considerable damage caused by NaCl prompted a DOT/FHWA sponsored search for an alternate highway deicing agent that would be cost competitive in the long run (2). Calcium magnesium acetate (CMA) has been selected as one of the most likely candidates. Although more expensive initially, CMA, unlike NaCl, tends to inhibit corrosion. While some qualitative studies of the corrosiveness of CMA have been made for a few metals, more comprehensive quantitative studies have been needed to supply the information necessary to properly evaluate its long term cost effectiveness.

PROCEDURE

Representative specimens were selected for most of Michigan's currently used highway structural metal applications with special attention being given to those most directly exposed to highway deicing salts. The

following groups of metals are represented identically in both exposure environments.

1) Bridge Steels:

ASTM A572, A588, A588 previously exposed to NaCl environments, and A36.

2) Bar Reinforcement for Concrete:

Plain - ASTM A706 or Grade 60 of either A615 or A616 or A617.
Epoxy Coated - ASTM D3963.
Stainless and Stainless Clad - AISI 300 Series.

3) Aluminum:

Sign Materials - Aluminum alloys 2024, 5052, and 6063T6.
Bridge Expansion Joint - Aluminum alloy 6061T6.

4) Prestressing Strand:

ASTM A416 Grade 270.

5) Galvanizing:

Bridge Expansion Joint - ASTM A715 Grade 50 with ASTM A153 Coating.
Steel Post (Brace) - ASTM A36 with ASTM A123 Coating.
Bridge Guard Railing - ASTM A500 Grade B with ASTM A153 Coating.

6) Galvanic Couples:

Galvanized Fastener ASTM A153/Aluminum - Aluminum alloy 6063T6.
Stainless Steel Fastener - AISI Series 300/Aluminum - Aluminum alloy 6063T6.
Stainless Steel Nut AISI Series 300/Galvanized Bolt - ASTM A153.

7) Guardrail:

Weathering Steel - AASHTO M180 Class B Type 4.
Galvanized - AASHTO M180 Class B Type 2.

The initial condition (prior to weathering) of all specimens is illustrated in Figures 1 through 7. In almost all cases, four essentially identical specimens were prepared of each material for both test environments. Sizes of the specimens are such that the total surface area of a specimen may vary from 10 to 35 sq in. The bridge steels and the weathering steel guardrail were sandblasted to remove all mill scale and surface oxide.

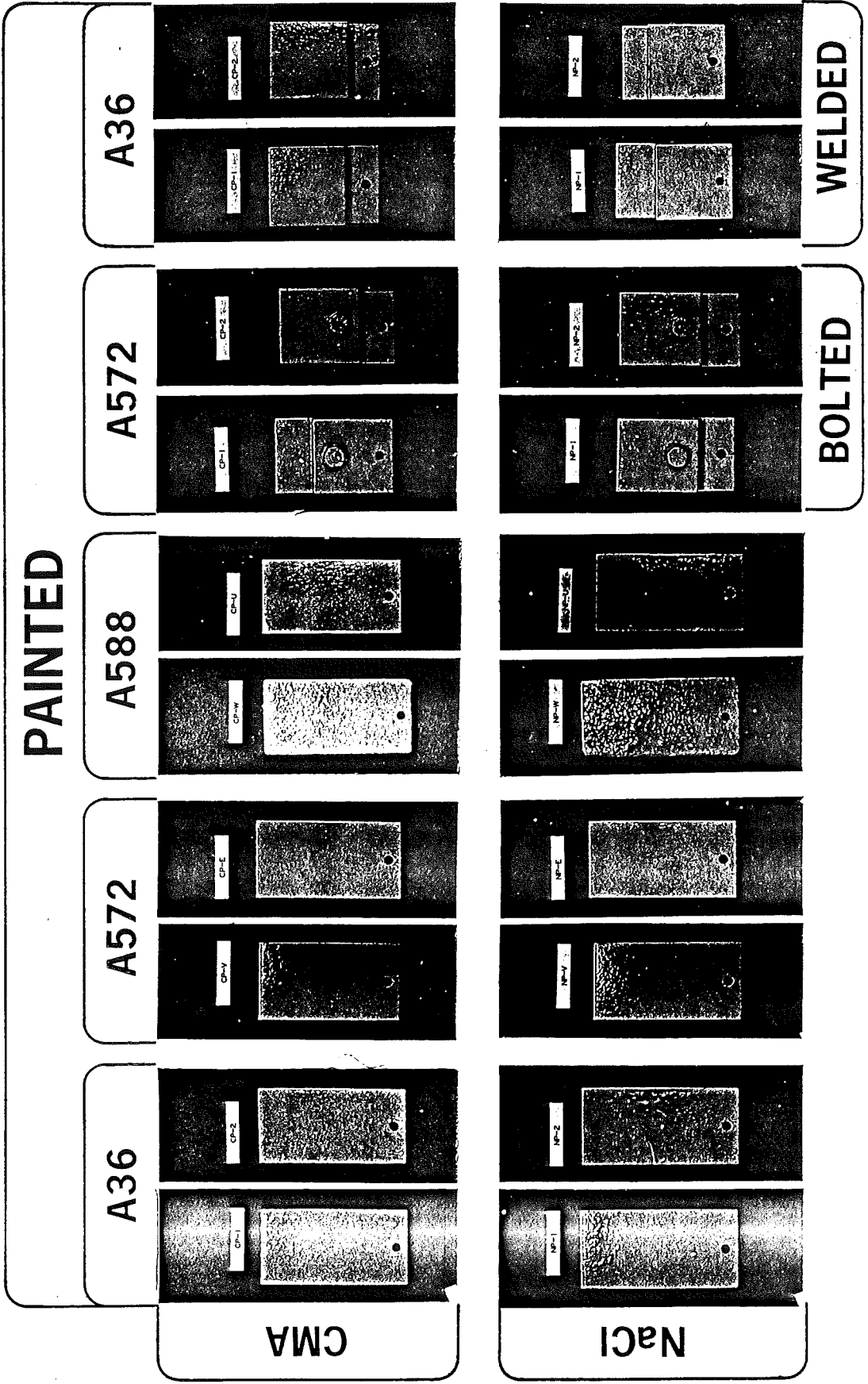


Figure 1. Structural (bridge) steels.

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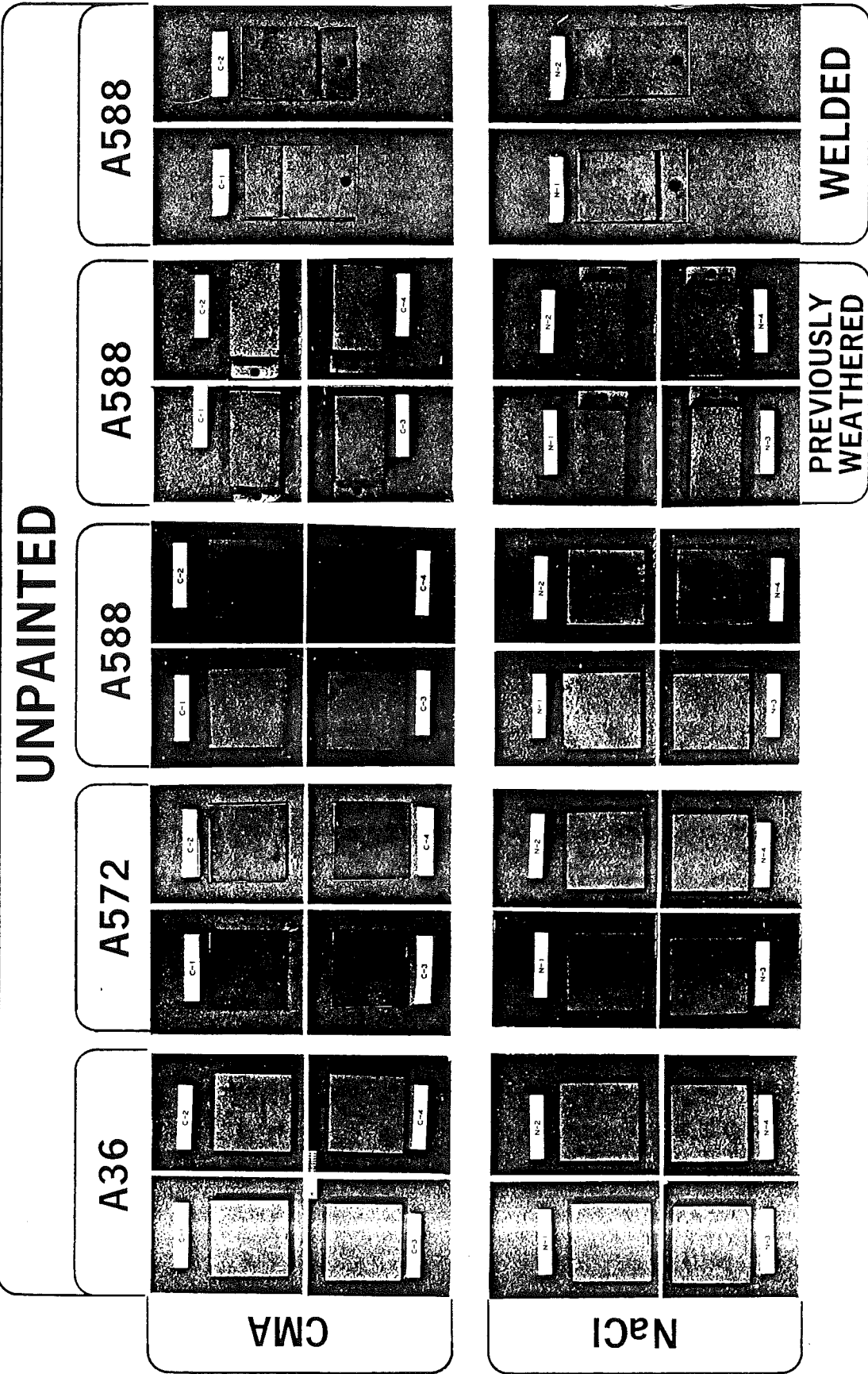


Figure 1 (cont). Structural (bridge) steels.

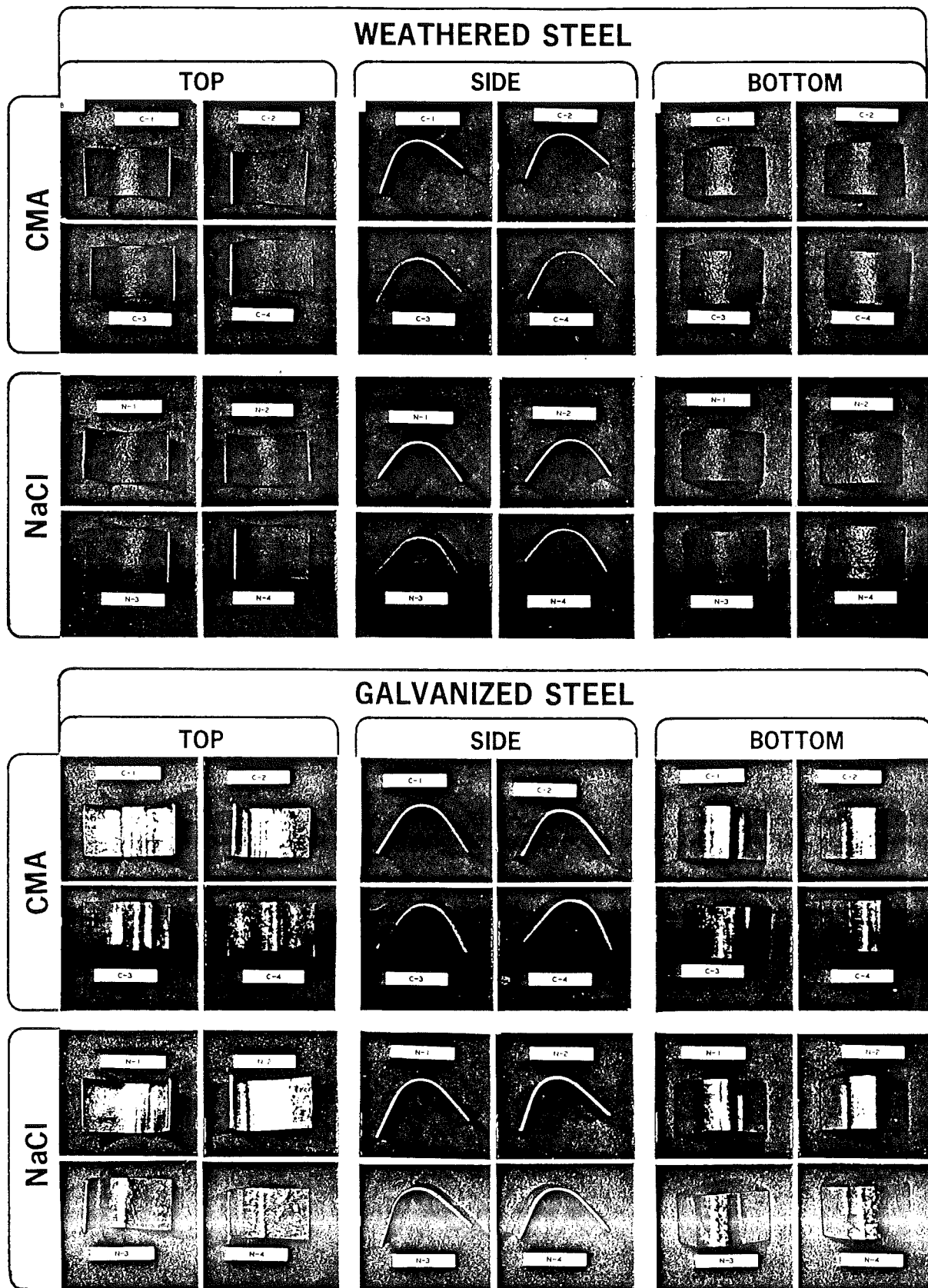


Figure 2. Weathering steel and galvanized guardrail.

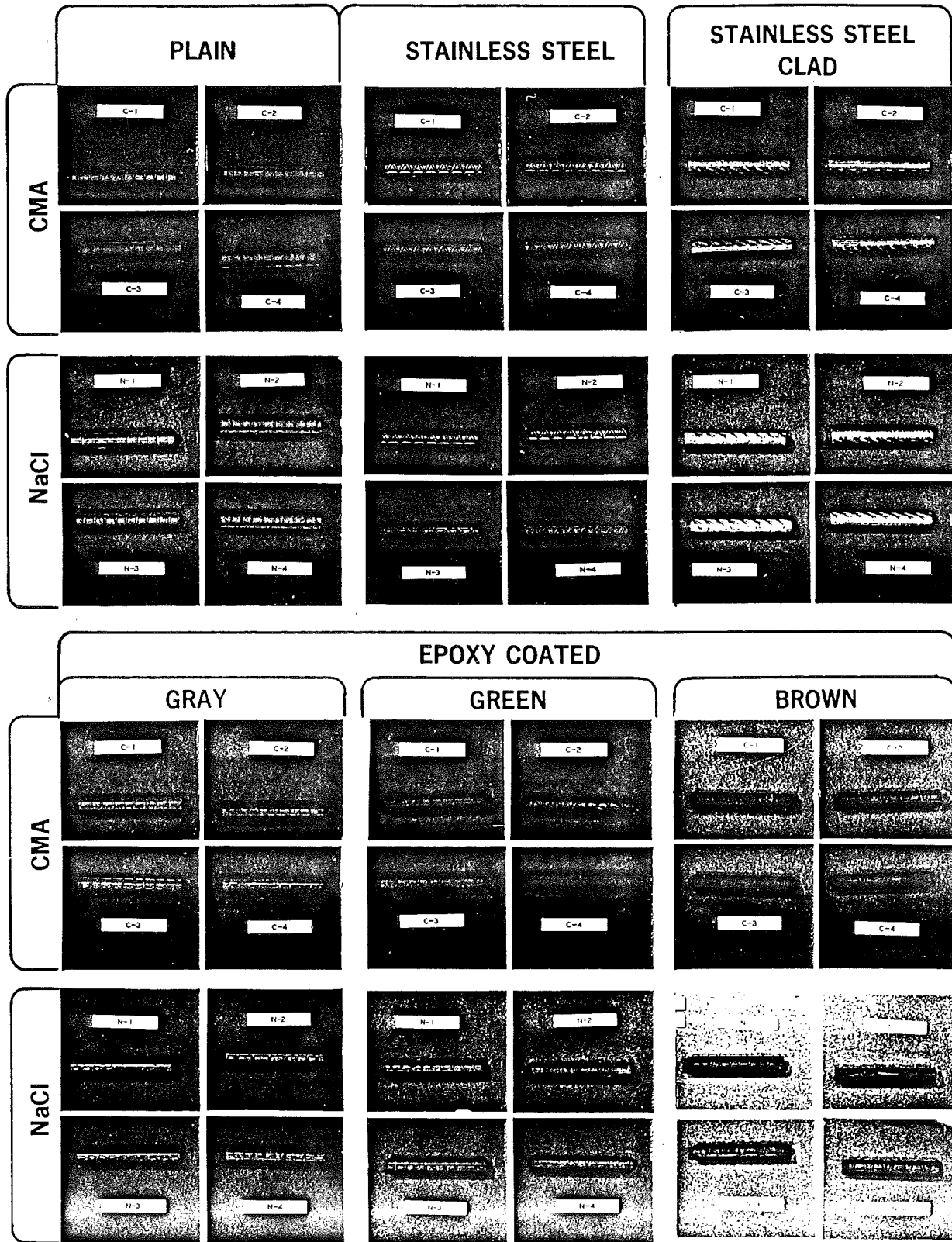


Figure 3. Bar reinforcement for concrete.

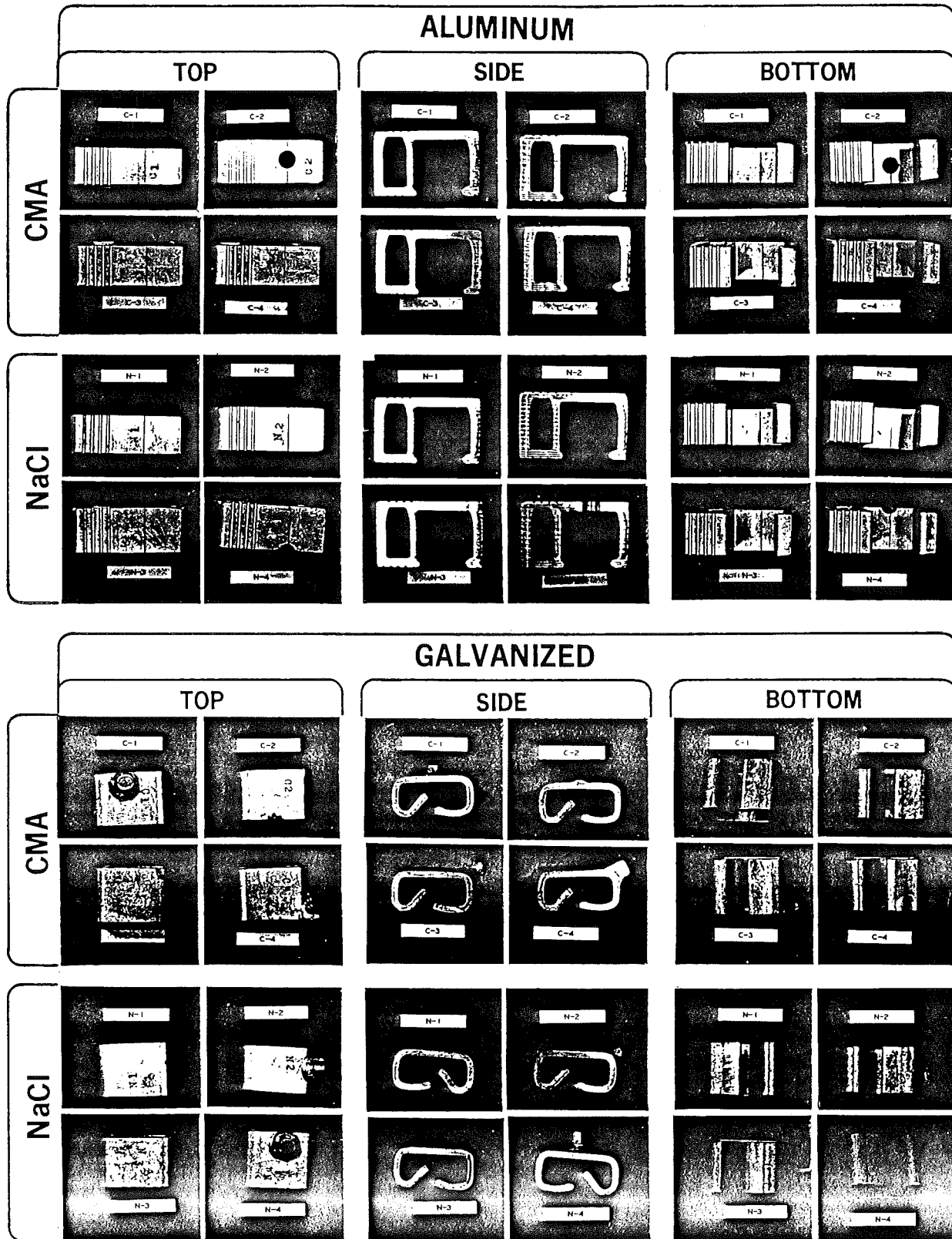


Figure 4. Bridge expansion joints.

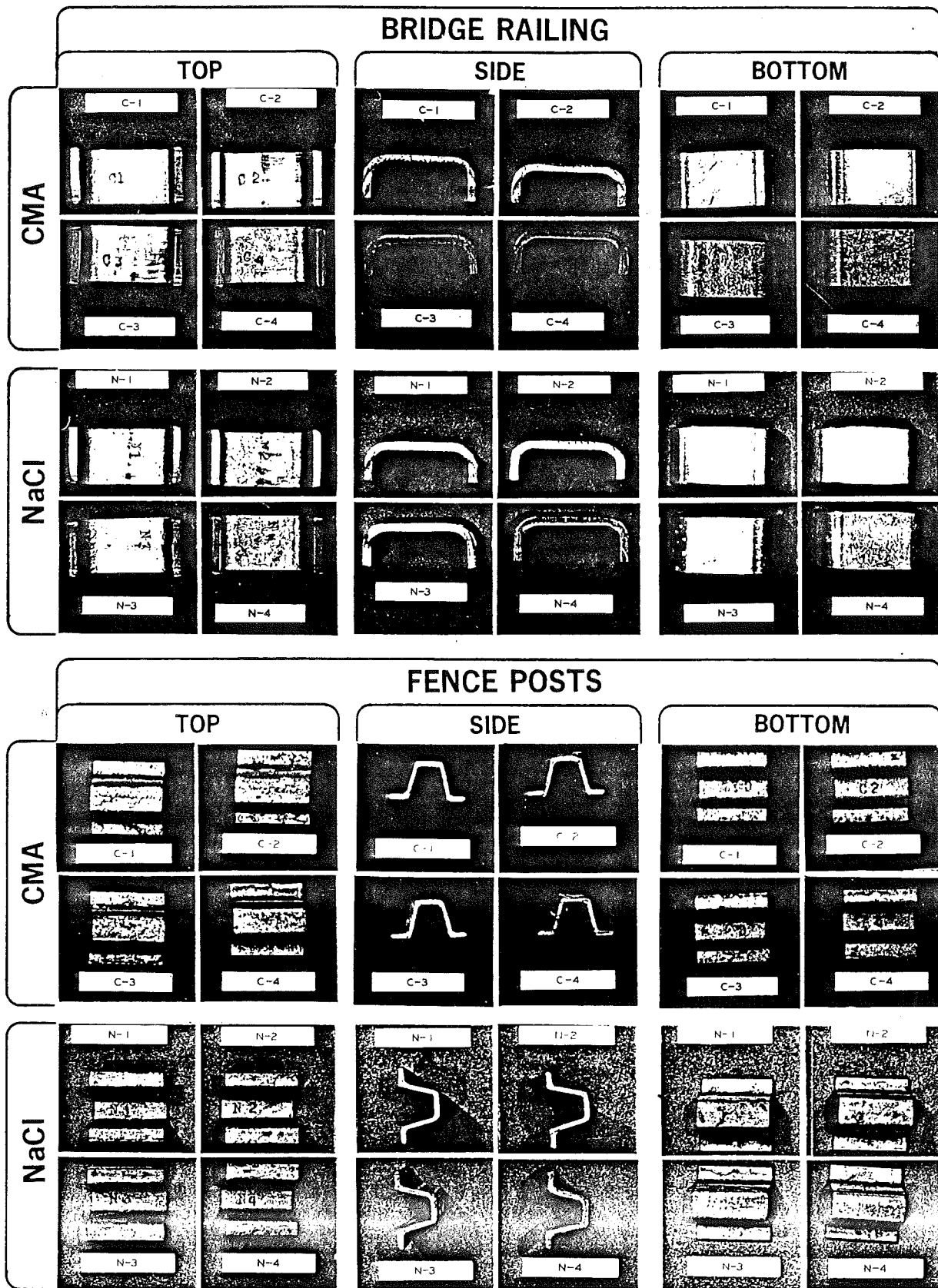


Figure 5. Miscellaneous galvanized materials.

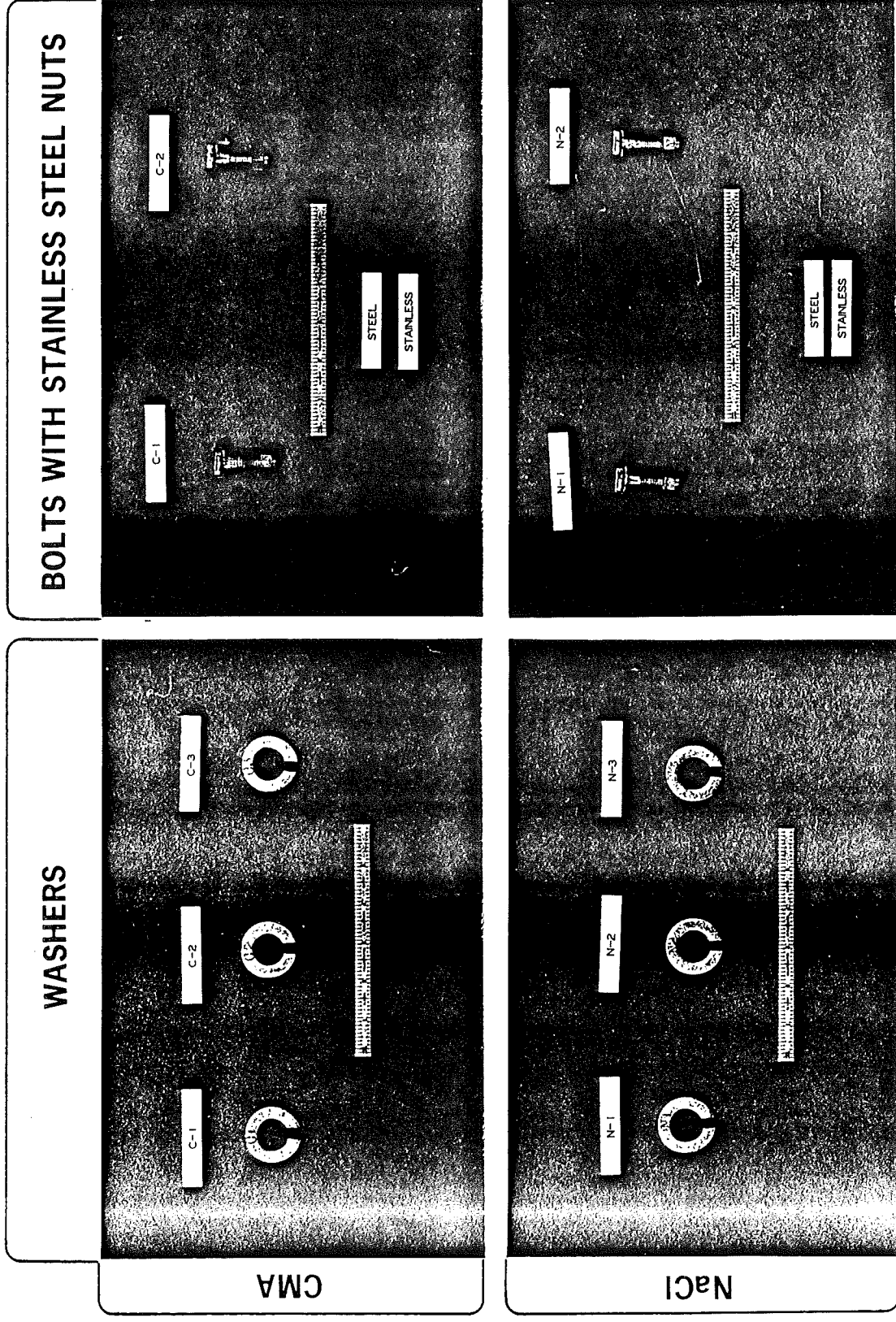


Figure 5 (cont). Miscellaneous galvanized materials.

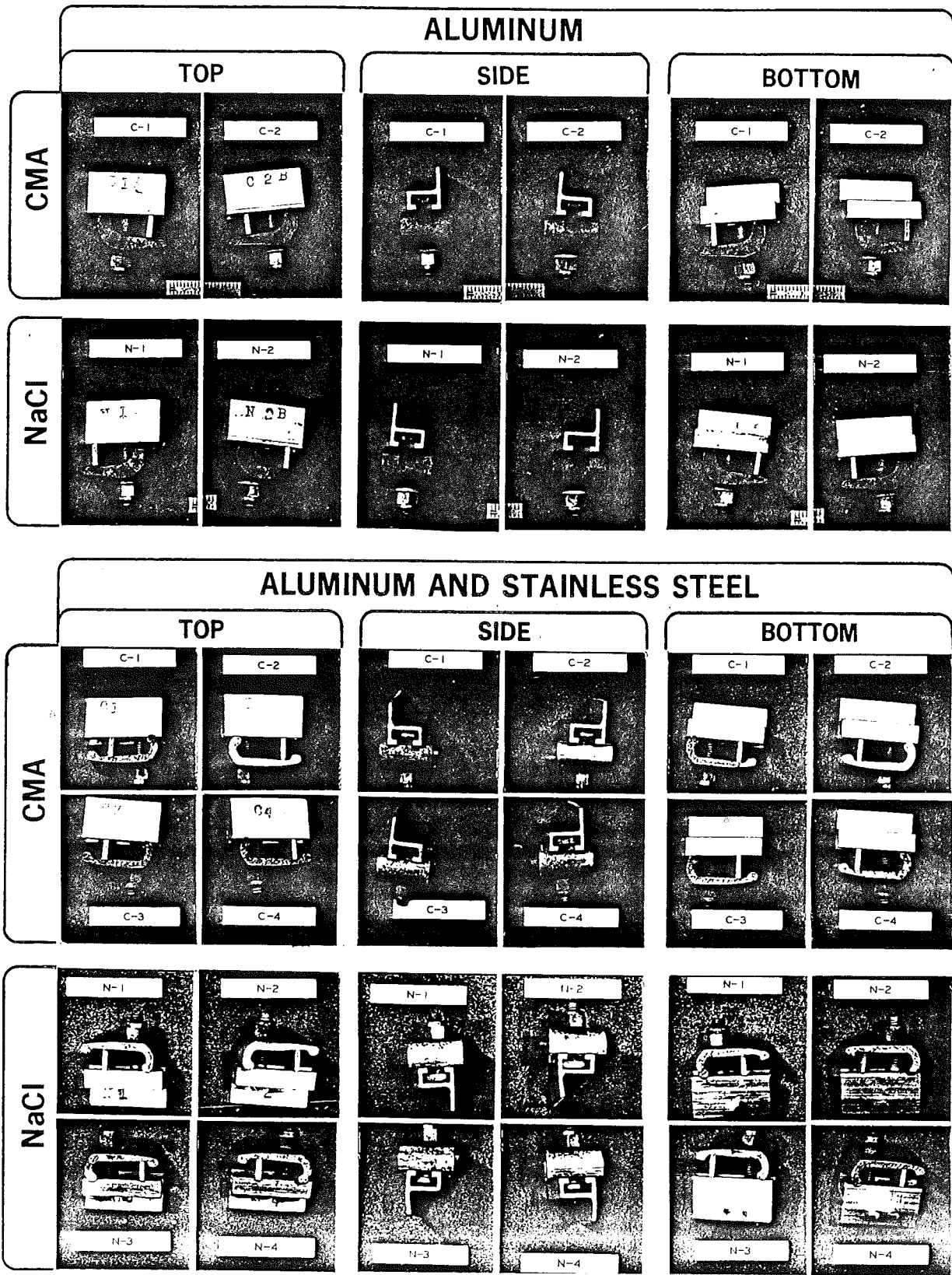


Figure 6. Aluminum sign sheeting.

All specimens were weighed and measured. The prestressing strand specimens were placed inside lengths of heavy electrical conduit, two strands to a conduit. The conduit provided both a dark, continuously moist environment that would more closely match the worst environments such strands might actually be exposed to, as well as a support frame which would allow the strands to be tensioned to typical service loads. For each conduit one strand was loaded in tension to approximately 70 percent of ultimate strength (28,900 lb) and end-anchored, while the other strand was left unloaded.

An environmental weathering chamber was constructed to house the specimens for exposure to CMA and NaCl environments (Fig. 8). Separate tanks hold CMA and NaCl solutions while a common shaft rotating at intervals periodically submerges the specimens. Rotation rate of the shaft is such that four complete revolutions are made each day. Dimensions of the chamber and the fluid level within the tanks are such that the specimens are submerged for approximately one-third of the time. Sufficient specimens of most materials were prepared to allow removal at intervals of three months, for a year.

The common hood for both tanks houses ultraviolet lamps to simulate sunlight and heating units to maintain an elevated temperature (115 to 120 F). The elevated temperature and, to some extent, the simulated sunlight both aid in drying the specimen before the next wetting and help accelerate corrosion so that differences between the CMA and NaCl specimens will be more apparent.

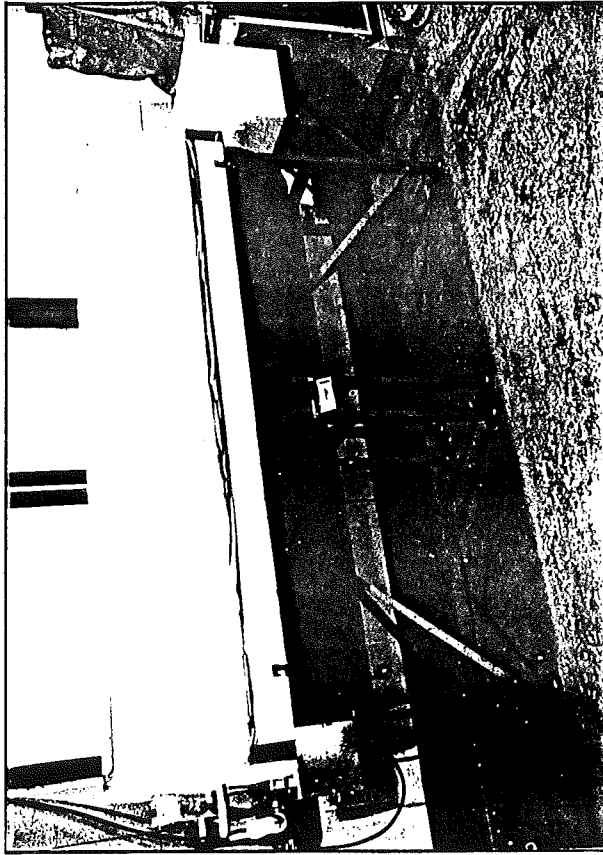
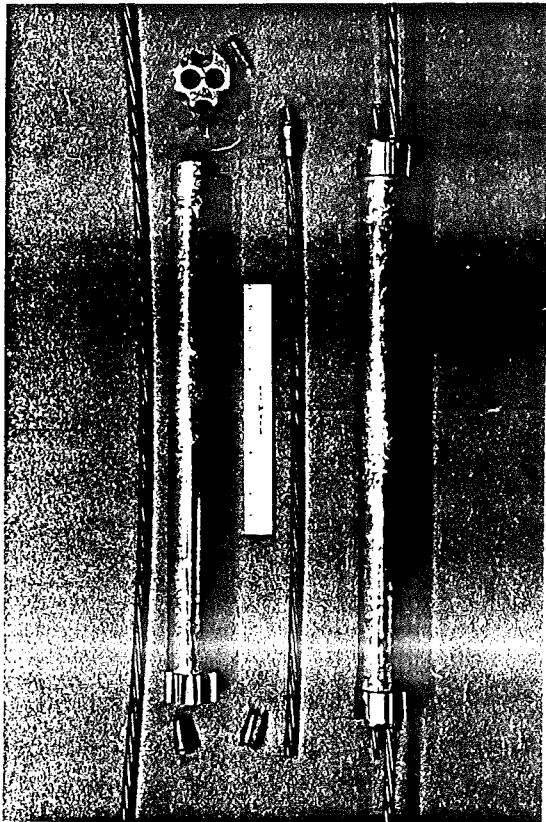
Specimens were degreased with an organic solvent prior to being mounted on rods projecting from the common rotating shaft. Six rows of eight rods were used in each tank for mounting the specimens.

Nylon fasteners were used in order to electrically isolate the specimens from each other, thus minimizing galvanic (dissimilar metal) corrosion effects between different specimens. Specimens were mounted in identical patterns in both tanks so that any galvanic corrosion effects that might occur when the specimens were submerged would be approximately the same in both tanks.

Concentrations (by weight) for the two solutions were initially set at 3.5 percent for the NaCl and 6.125 percent for the CMA, these being concentrations that would have equivalent deicing (freezing point depression) abilities. Since a greater concentration of CMA must be used for deicing it has seemed appropriate to reflect this difference in our exposure environments. The NaCl was taken from one of our highway maintenance garages and is typical of that normally used in Michigan for highway deicing.* The CMA was taken from the 98 tons furnished by the FHWA for field evaluations.* (This is part of the 200 ton batch produced in 1982 by the FHWA sponsored pilot plant in Bowling Green, Kentucky.) Distilled water has been used to both prepare the initial solutions and maintain fluid level within the tanks. Fluid level is automatically con-

*See Appendix

Figure 7. Prestressing strand for concrete and test assembly.



- a) Enclosed - hood contains heating elements and ultraviolet lighting.
- b) With hood removed and specimens exposed (CMA on left and NaCl on right).

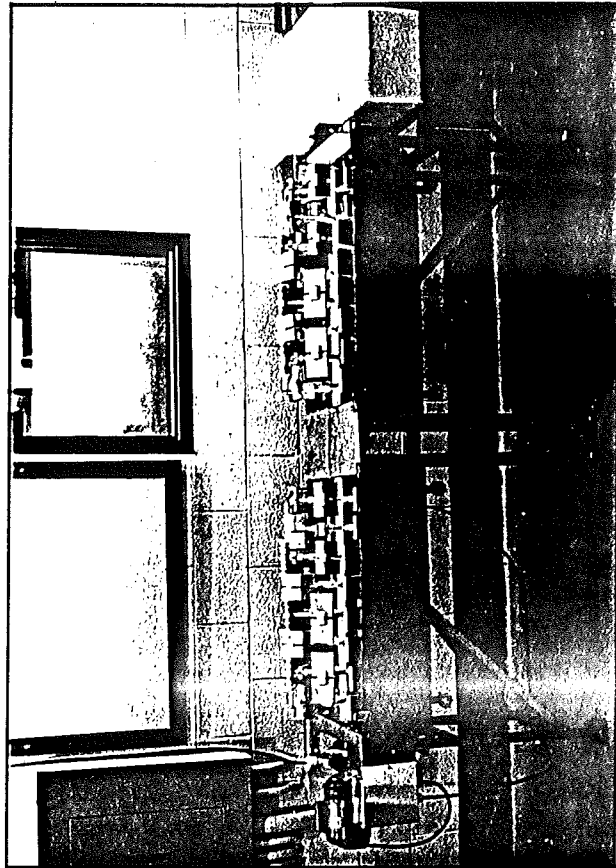


Figure 8. Environmental weathering chambers.

trolled via floats in adjacent tank reservoirs so that changes in solution concentration are minimized.

The first group of specimens was removed after about three months (107 days) for evaluation. The surface oxide was removed from all specimens in accordance with the appropriate procedure (for a given material) specified in ASTM G1. All specimens were reweighed and weight losses determined. Knowing the original dimensions of the specimens, corrosion rates were calculated. For those specimens with relatively non-uniform pitting, pit depths were measured for the worst pits and worst case pitting rates were calculated. All specimens were also examined for any peculiarities which might be of interest or importance.

The prestressing strand specimens were tested in tension to ultimate failure along with several control samples to determine losses in ultimate tensile strength.

For the galvanized specimens, pre- or post-test thickness measurements were made of the galvanizing using a positector calibrated on National Bureau of Standards Coating Thickness specimens. The percentage of the surface still galvanized was evaluated where appropriate. A control specimen was included during the cleaning (oxide removal) process to estimate the loss of galvanizing resulting from the cleaning.

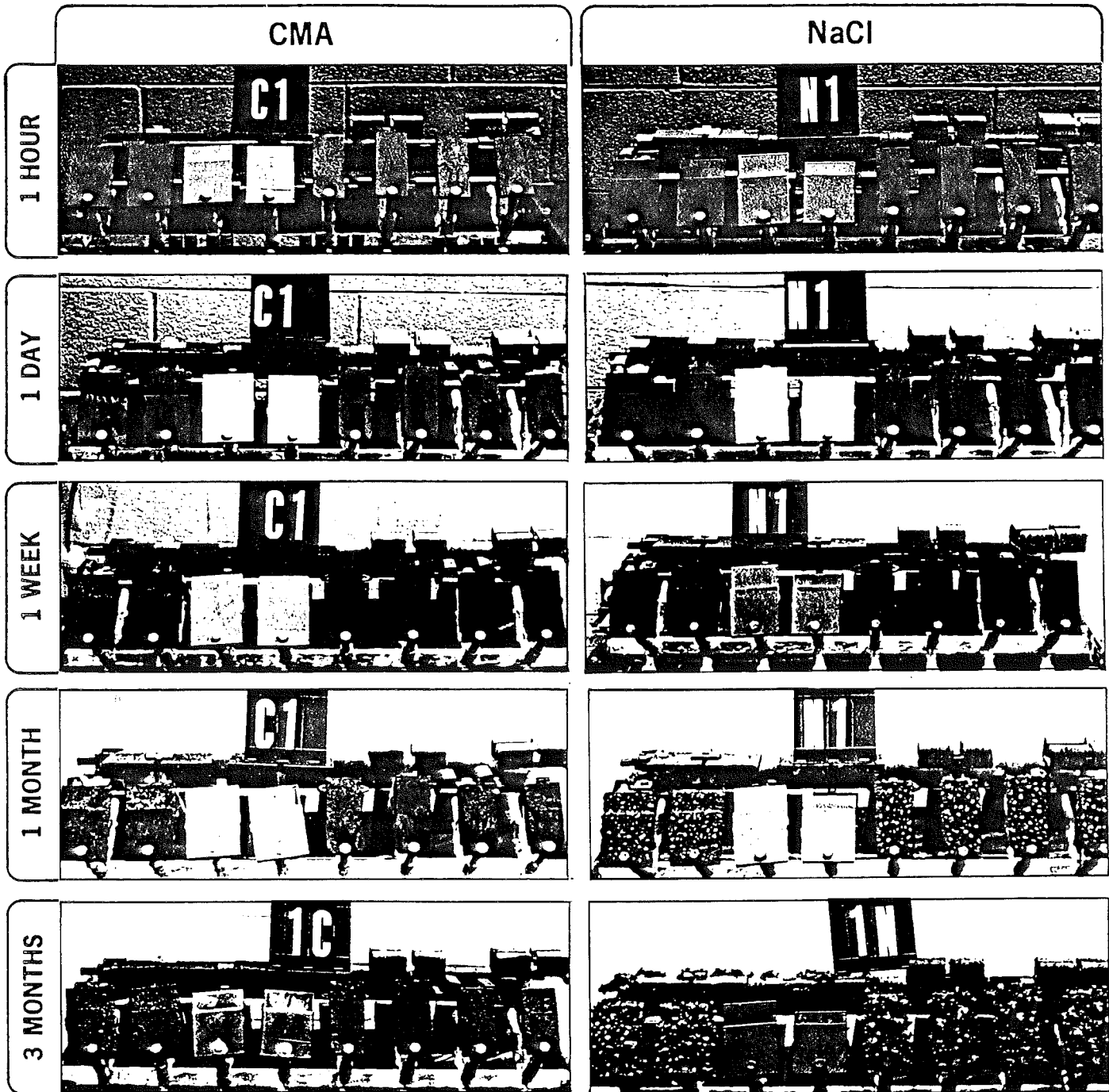
For the epoxy coated rebar specimens, sufficient epoxy was removed from the cut ends to evaluate the extent of rust undercutting.

RESULTS AND DISCUSSION

Qualitative observation of the CMA and NaCl specimens from only several hours of exposure onward have consistently indicated considerably worse corrosion occurring in the NaCl environment. Figure 9 illustrates the visual differences for initially identical sets of specimens in these two environments after one hour, one day, one week, one month and three months. At no time during the first three months of exposure was there any indication that the CMA environment was anywhere near as corrosive as the NaCl environment.

Major results of the specimen evaluation are revealed in Tables 1 through 4 and Figure 10. The weathered condition of all the materials removed after three months exposure (three and six months for the steel prestressing strand) is illustrated in Figures 11 thru 18. All of the metals and metal coatings tested performed markedly better in the CMA environment. On the average, the CMA environment was only one-third to one-ninth as corrosive as the NaCl environment. Some of the more significant results are discussed in more detail for the individual metal groups.

While the exposure environment used in this study is an accelerated weathering environment, all specimens have been treated identically.



SPECIMEN IDENTIFICATION: (left to right for both tanks)
 1) A588 welded lap-loose; 2) A588 welded lap-tight; 3) Painted A 36 welded lap-tight; 4) Painted A36 welded lap-loose; 5) thru 8) A588 previously weathered in a NaCl environment.

Figure 9. Visual time lapse comparison between the CMA and NaCl environments over the first three months.

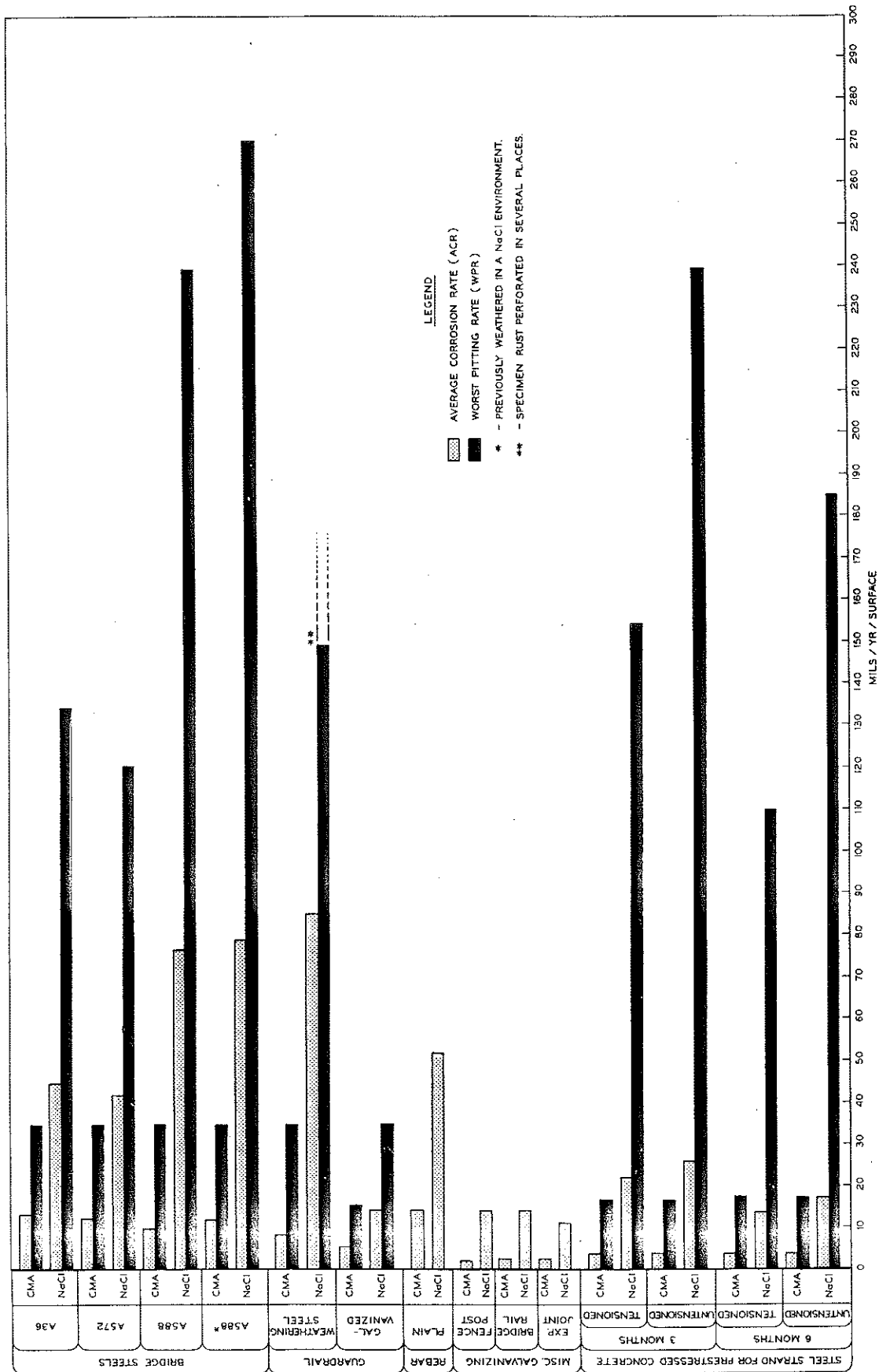


Figure 10. Summary of average corrosion rates and worst pitting rates.

TABLE 1
CORROSION PERFORMANCE OF STRUCTURAL (BRIDGE) STEELS, GUARDRAIL BEAM MATERIALS,
BAR REINFORCEMENT FOR CONCRETE, AND ALUMINUM ALLOYS AFTER THREE MONTHS

Specimen	Original		Weight Loss, oz/%	Average Corrosion Rate (ACR), mils/yr/surface	Ratio, ACR, NaCl / ACR, CMA	Worst Pit Depth, mils	Worst Pitting Rate (WPR), mils/yr/surface	Ratio, WPR / ACR	Estimated Equivalent Exposure Duration, years ¹			
	Dimensions, in. x in. x in.	Surface Area, sq in.							Rural	Severe Industrial	Continuous Salt Water Immersion	Marine Beach
<u>Bridge Steels</u>												
A36 CMA NaCl	2.95 x 3.00 x .50	23.65	2.00	12.2	3.64	10	35	2.9	25.9	5.2	2.2	.32
	3.00 x 3.00 x .50	24.00	2.03	44.2		40	135	3.0				
A572 CMA NaCl	2.90 x 2.95 x .50	22.95	1.94	11.7	3.56	10	35	2.8	24.2	4.8	2.0	.30
	2.95 x 2.95 x .50	23.30	2.00	41.7		35	120	2.9				
A588 CMA NaCl	3.00 x 3.00 x .380	22.55	1.56	9.3	8.32	10	35	3.8	45.2	9.0	3.8	.56
	3.00 x 3.00 x .380	22.55	1.55	77.0		70	240	3.4				
A588 ² CMA NaCl	Irregular	31.30	4.15	11.8	6.77	10	35	2.9	46.6	9.3	3.9	.58
	Irregular	30.60	4.01	79.6		80	270	3.4				
<u>Guardrail</u>												
Weathering Steel CMA NaCl	4.75 x 1.90 x .090	19.25	0.380	8.8	9.60	10	35	4.0	49.4	9.9	4.1	.61
	4.90 x 2.00 x .090	22.80	0.402	84.3		>45 ³	>150	>1.8				
Galvanized CMA NaCl	5.30 x 2.00 x .110	22.80	0.510	4.9	2.94	< 5	<15	<3.0				
	5.40 x 2.05 x .110	23.80	0.538	14.4		10	35	2.3				
Rebar Plain CMA NaCl	Irregular	10.10	0.581	14.6	3.57							
	Irregular	10.10	0.584	52.0								
Stainless CMA NaCl	NEGLECTIBLE CORROSION											
	NEGLECTIBLE CORROSION OF STAINLESS CLADDING BUT SOME CORROSION OF PLAIN CARBON STEEL AT UNPROTECTED CUT ENDS											
Epoxy - Gray, Green, Brown CMA NaCl	NEGLECTIBLE EFFECT ON EPOXY COATING											
	Negligible corrosion at unprotected cut ends CMA Minor corrosion at unprotected cut ends NaCl											
<u>Aluminum</u>												
CMA NaCl	NEGLECTIBLE CORROSION											
	NEGLECTIBLE AVERAGE CORROSION BUT A FEW 5-10 MIL PITS											

¹ Corrosion rates used in estimations are representative of those reported by ASM for plain carbon steels - .5 mils/yr for rural, 2.5 mils/yr for severe industrial, 6 mils/yr for continuous salt water immersion, and 40 mils/yr for marine beach.
² Previously weathered in NaCl environment.
³ Rust perforated in several spots.

TABLE 2
CORROSION PERFORMANCE OF GALVANIZING AFTER THREE MONTHS

Specimen	Original		Weight Loss, oz/%	Average ¹ Corrosion Rate (ACR), mils/yr/surface	Ratio, ACR, NaCl / ACR, CMA	Original Thickness, mils	Weathered ² Thickness, mils	Surface Area Still Galvanized, percent	Approximate Equivalent Exposure Duration, years ^{3,4}			Comments
	Dimensions, in. x in. x in.	Surface Area, sq in.							Weight, oz.	Rural	Severe Industrial	
Fence Post CMA NaCl	Irregular	14.53	3.80	0.029/.76	8.81	5.0	2.6	100	67.9	9.9	1.7	4
		14.40	3.62	0.252/6.97								
Bridge Rail CMA NaCl	Irregular	16.38	7.20	0.048/.66	5.60	3.7	2.8	100	48.6	7.1	1.2	
		15.68	6.80	0.255/3.66								
Expansion Joint CMA NaCl	Irregular	36.60	17.40	0.086/.49	5.28	2.7	1.7	95	27.7	4.04	.7	
		36.50	16.30	0.451/2.76								
Guretrail CMA NaCl	5.30 x 2.00 x .110 5.40 x 2.05 x .110	22.81	0.51	0.013/2.62	2.94	4.0	1.8	95	55.1	8.0	1.4	
		23.78	0.54	0.041/7.62								

¹ Based on weight loss.

² Based on change in zinc coating thickness measured by a positector.

³ Typical zinc corrosion rates for various environments are taken from ASM reference materials - 0.07 mils/yr for rural, .48 mils/yr for severe industrial, and 2.8 mils/yr for continuous water immersion.

⁴ Some corrosion of base metal.

TABLE 3
STEEL STRAND FOR PRESTRESSED CONCRETE (ASTM A416)
CORROSION DATA

	Specimen	Strand ¹ Length, in.	Original		Weight Loss oz/%	Average Corrosion Rate (ACR), mils/yr surface	Ratio, $\frac{\text{ACR, NaCl}}{\text{ACR, CMA}}$	Worst Pit Depth, mils	Worst Pitting Rate (WPR), mils/yr/ surface	Ratio, $\frac{\text{WPR}}{\text{ACR}}$
			Surface Area, sq in.	Weight, oz.						
3 months	Tensioned									
	CMA	29.94	110.0	20.61	0.648/3.14	4.4	5.05	5	17.1	3.8
	NaCl	29.81	109.5	20.52	3.231/15.7	22.2		45	155	6.7
	Untensioned									
	CMA	29.94	110.0	20.61	0.628/3.05	4.3	5.98	5	17.1	4.0
	NaCl	29.69	109.5	20.44	3.732/18.3	25.7		70	240	9.3
6 months	Tensioned									
	CMA	29.88	110.0	20.56	1.111/5.4	4.1	3.44	10	18.3	4.5
	NaCl	29.50	109.0	30.31	3.825/18.8	14.1		60	110	7.8
	Untensioned									
	CMA	30.13	110.5	20.74	1.171/5.6	4.3	4.30	10	18.3	4.2
	NaCl	29.63	109.5	20.40	5.021/24.6	18.5		100	185	10.0

¹Center wire is 0.170 in. diameter and other wires are 0.164 in. diameter.

TABLE 4
STEEL STRAND FOR PRESTRESSED CONCRETE (ASTM A416)
PERFORMANCE DATA

	Specimen Environment	Ultimate Load, lb	Reduction in Ultimate Load From Control Specimen lb/percent	Reduction From ASTM A 416 Re- quired Ultimate Load (41,300) lb/percent	Elongation, Percent
Control	No. 1	≧ 43,070			3-1/2
	No. 2	≧ 43,490			—
	No. 3	≧ 43,510			2
	Average	≧ 43,025			
3 Months	CMA Tensioned	≧ 40,675	~2,350/~5.45	≤ 625/≤ 1.5	3-1/2
	CMA Untensioned	≧ 41,700	~1,325/~3.10	Greater Than	4
	NaCl Tensioned	29,470	≧ 13,550/≧ 32.50	11,830/28.65	2-1/2
	NaCl Untensioned	27,160	≧ 15,865/≧ 36.85	14,140/34.25	4-1/2
6 Months	CMA Tensioned	40,720	≧ 2,305/≧ 5.4	580/1.4	4
	CMA Untensioned	≧ 40,420	~2,605/~6.1	≤ 880/≤ 2.1	4
	NaCl Tensioned	26,700	≧ 16,325/≧ 37.9	14,600/35.4	1
	NaCl Untensioned	22,140	≧ 20,885/≧ 48.5	19,160/46.4	0

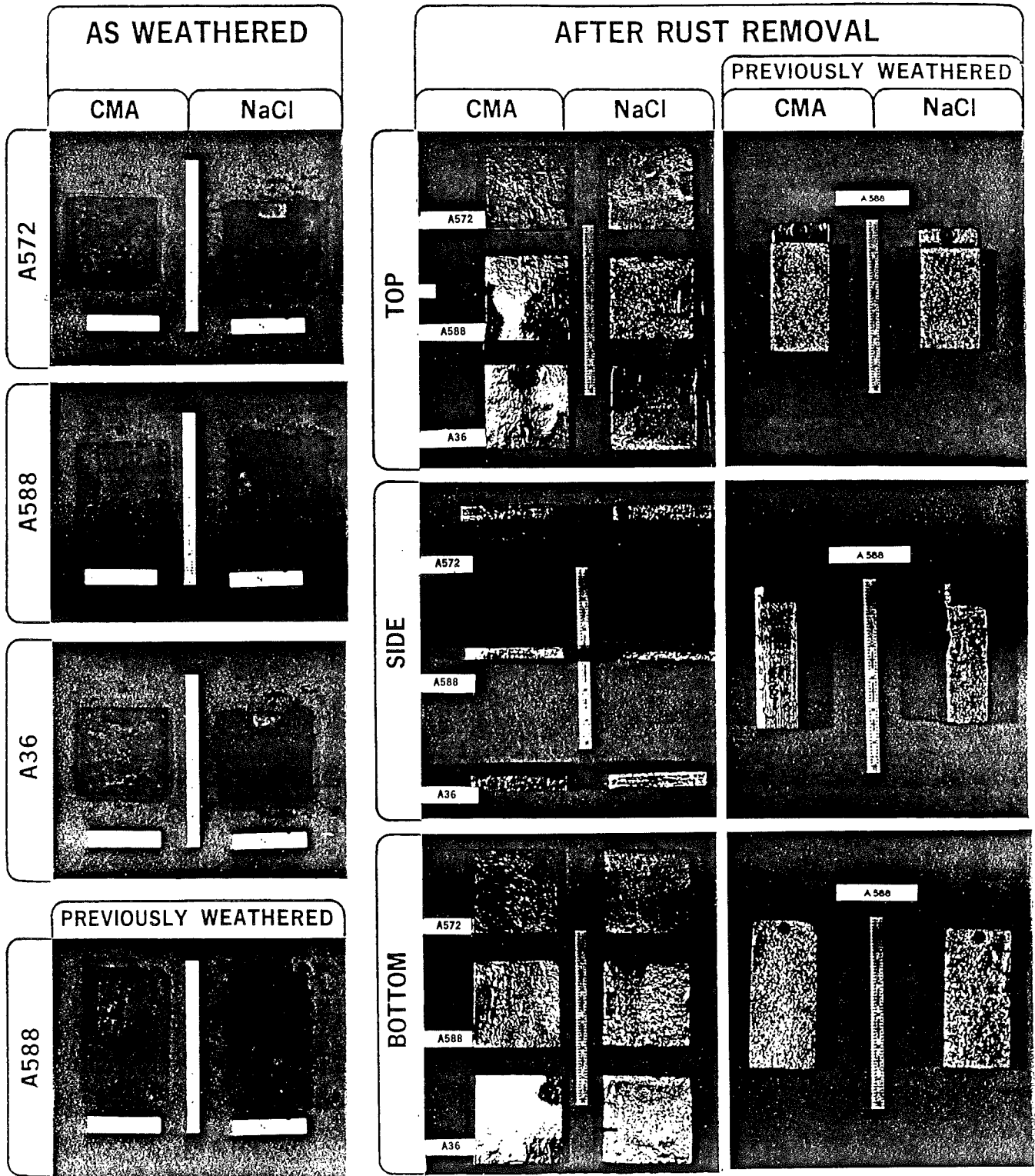


Figure 11. Structural (bridge) steels after three months exposure.

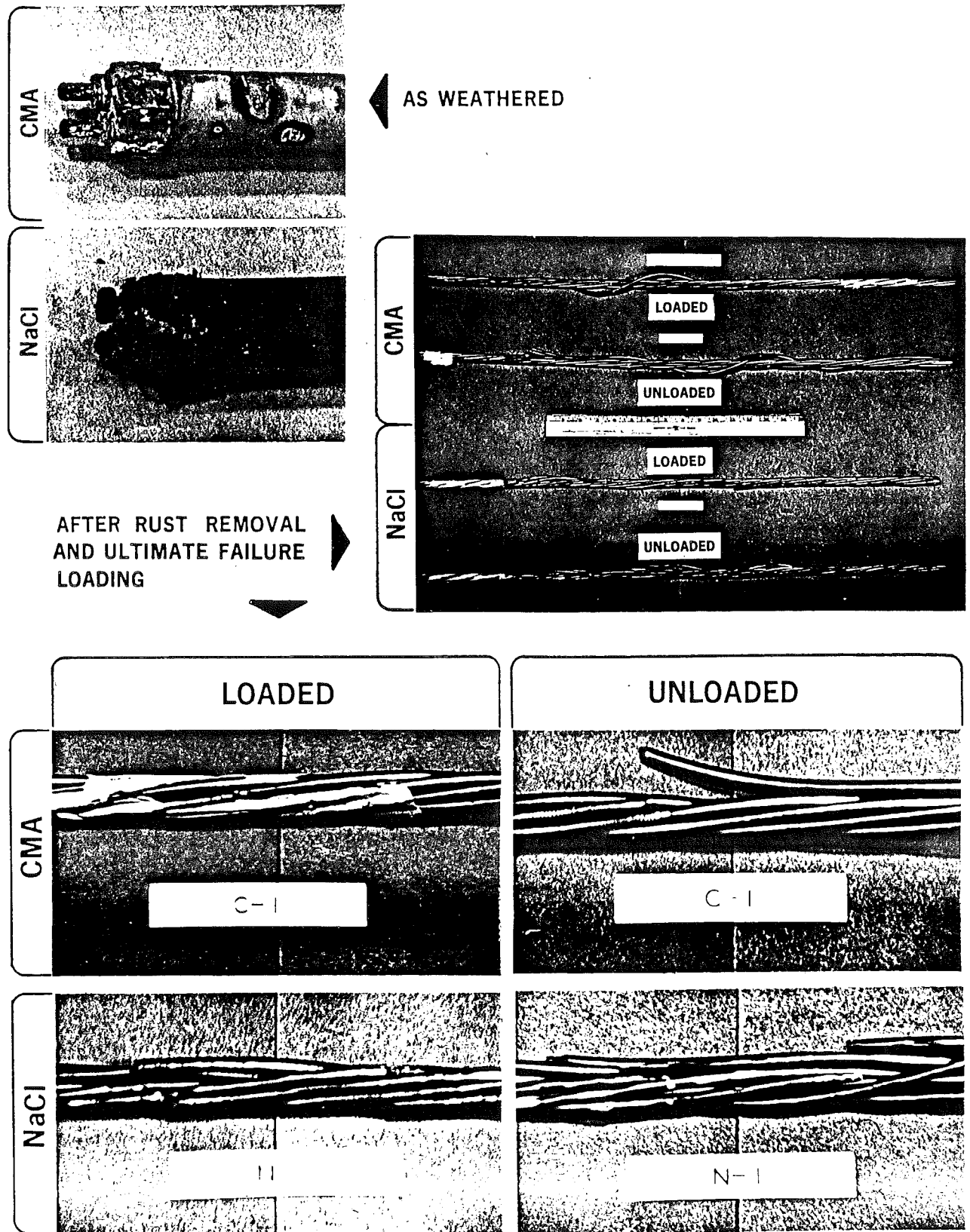


Figure 12. Steel prestressing strand for concrete after three months exposure.

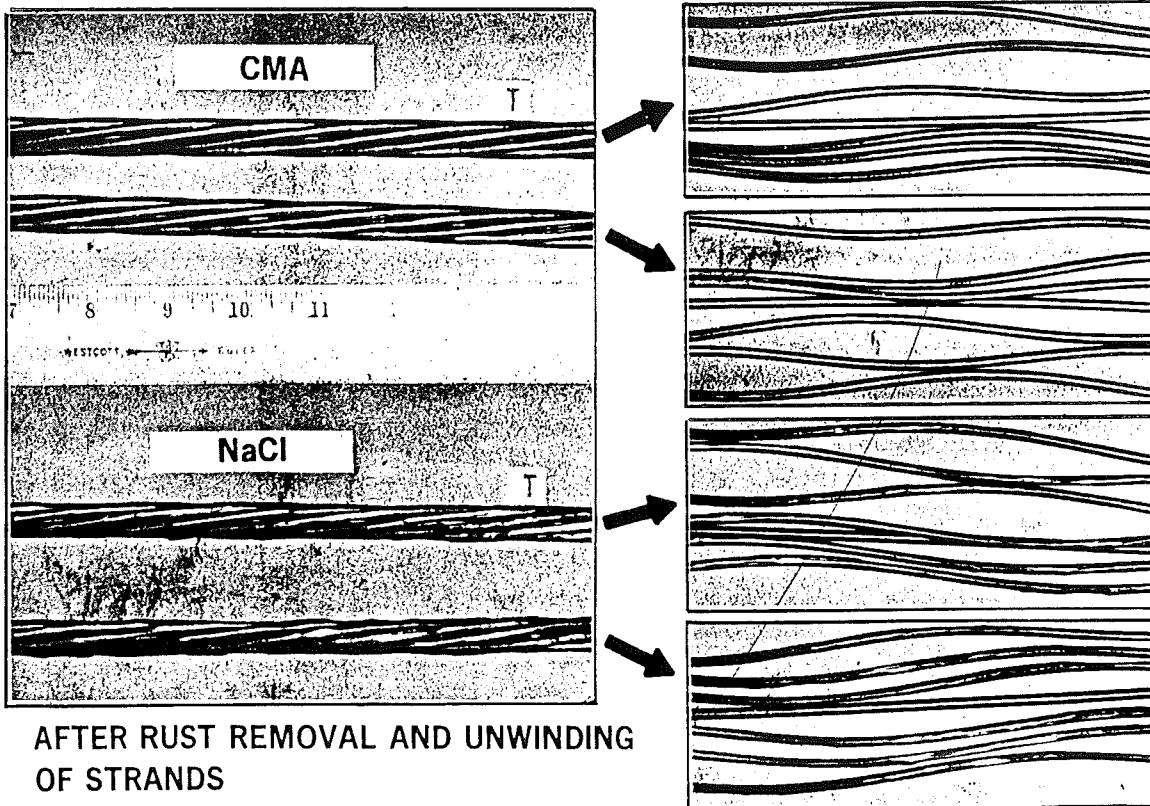
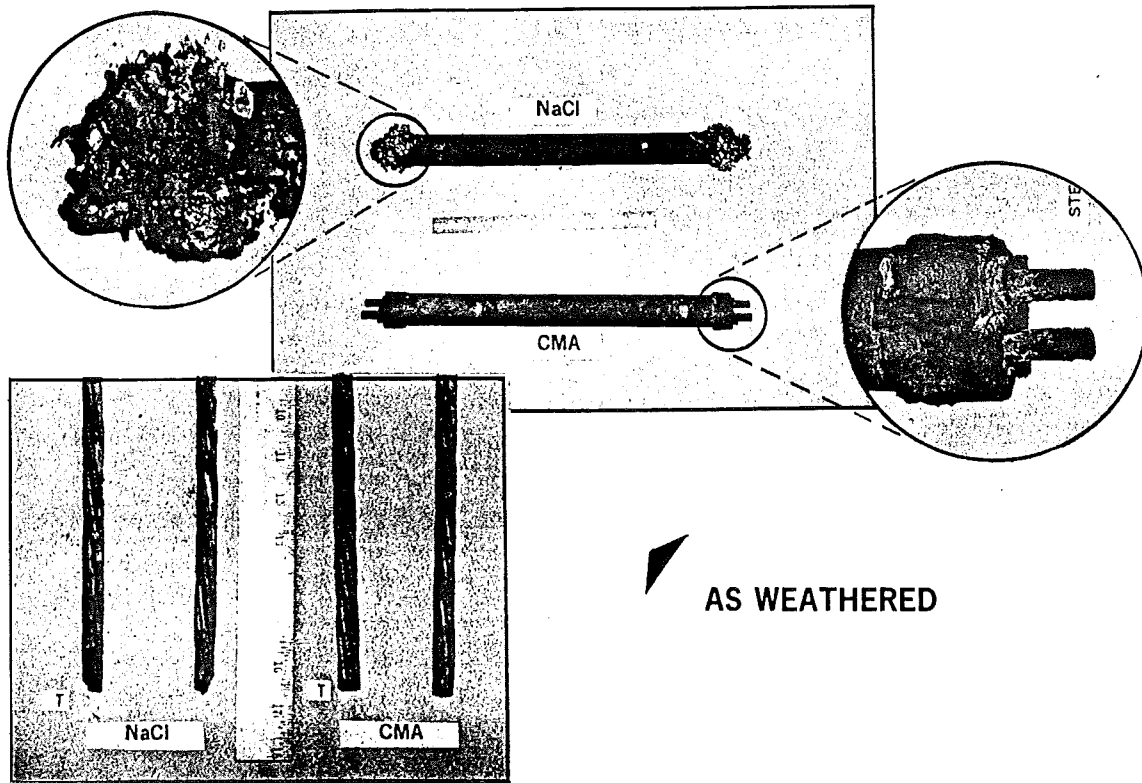


Figure 13. Steel prestressing strand for concrete after six months exposure (T indicates specimens that were under tensile load during exposure).

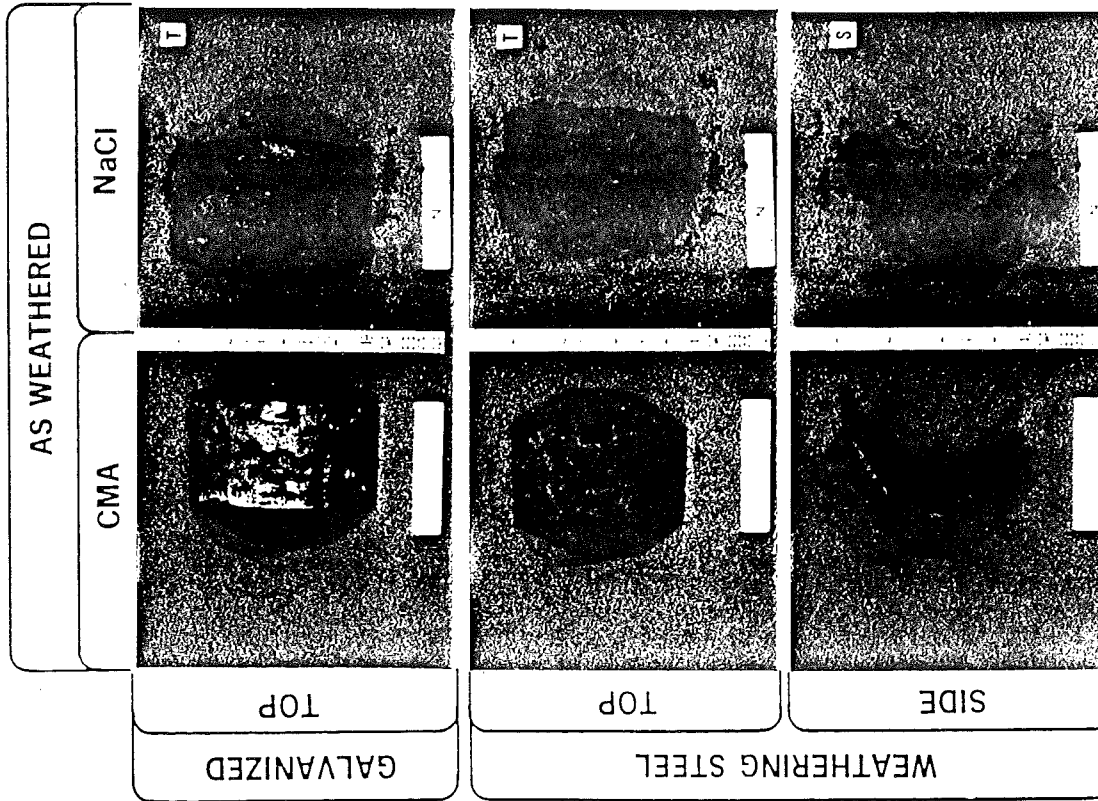
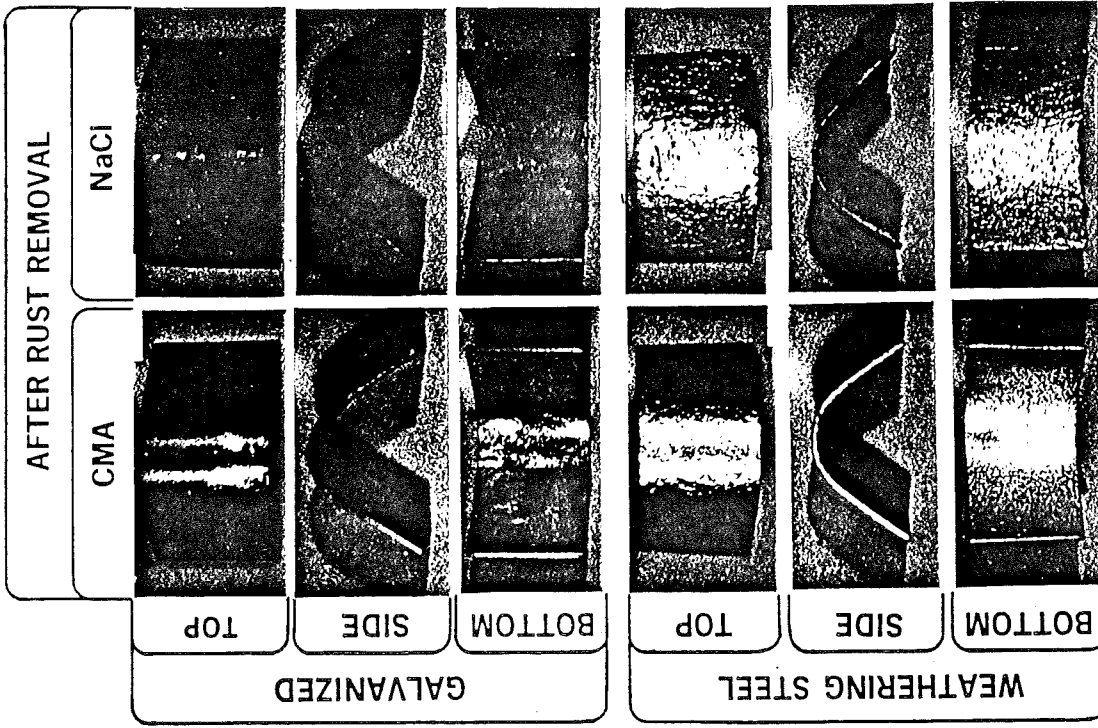


Figure 14. Guardrail after three months exposure.

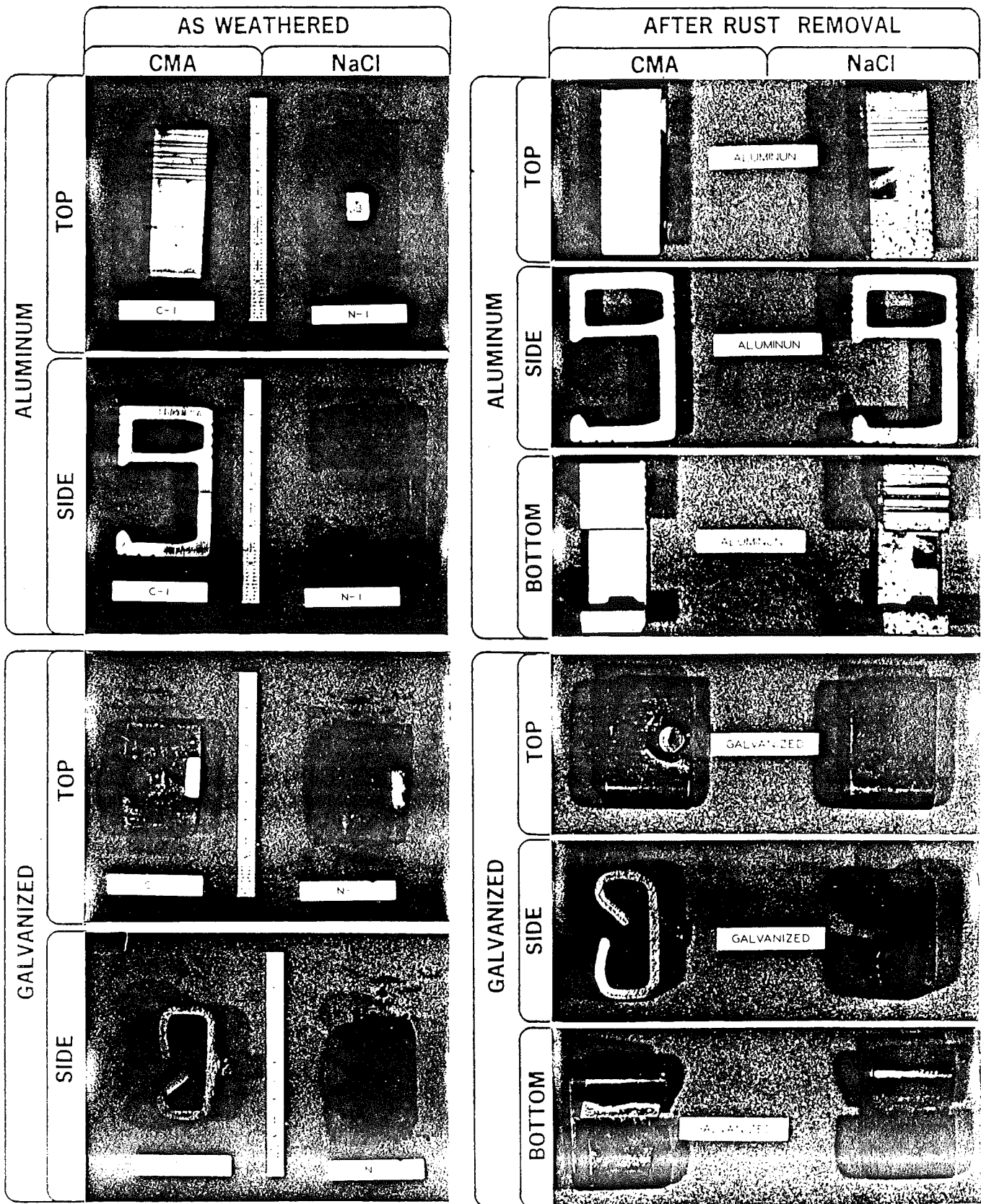


Figure 15. Expansion joint materials after three months exposure.

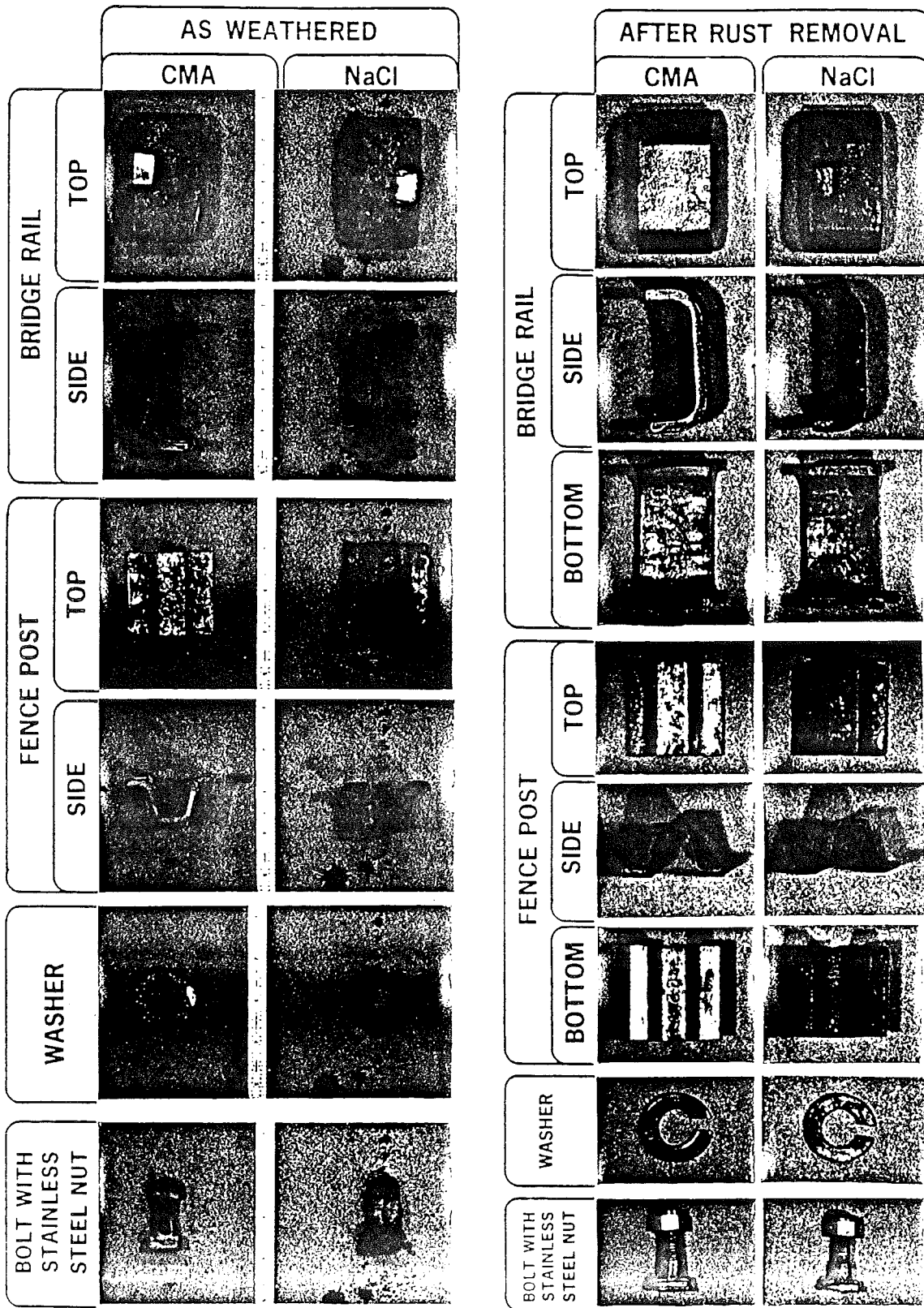


Figure 16. Miscellaneous galvanized materials after three months exposure.

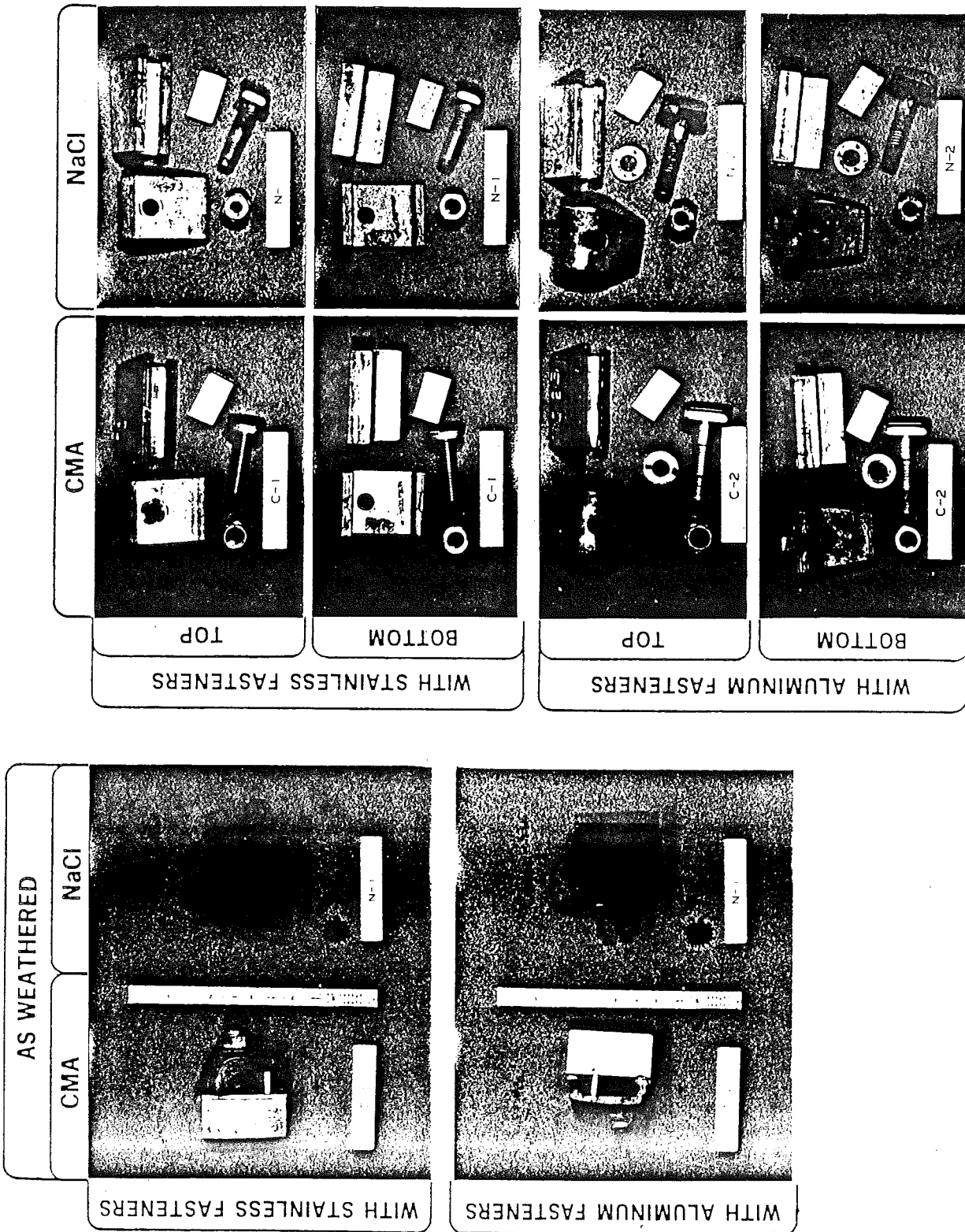


Figure 17. Aluminum sign sheeting with fasteners after three months exposure.

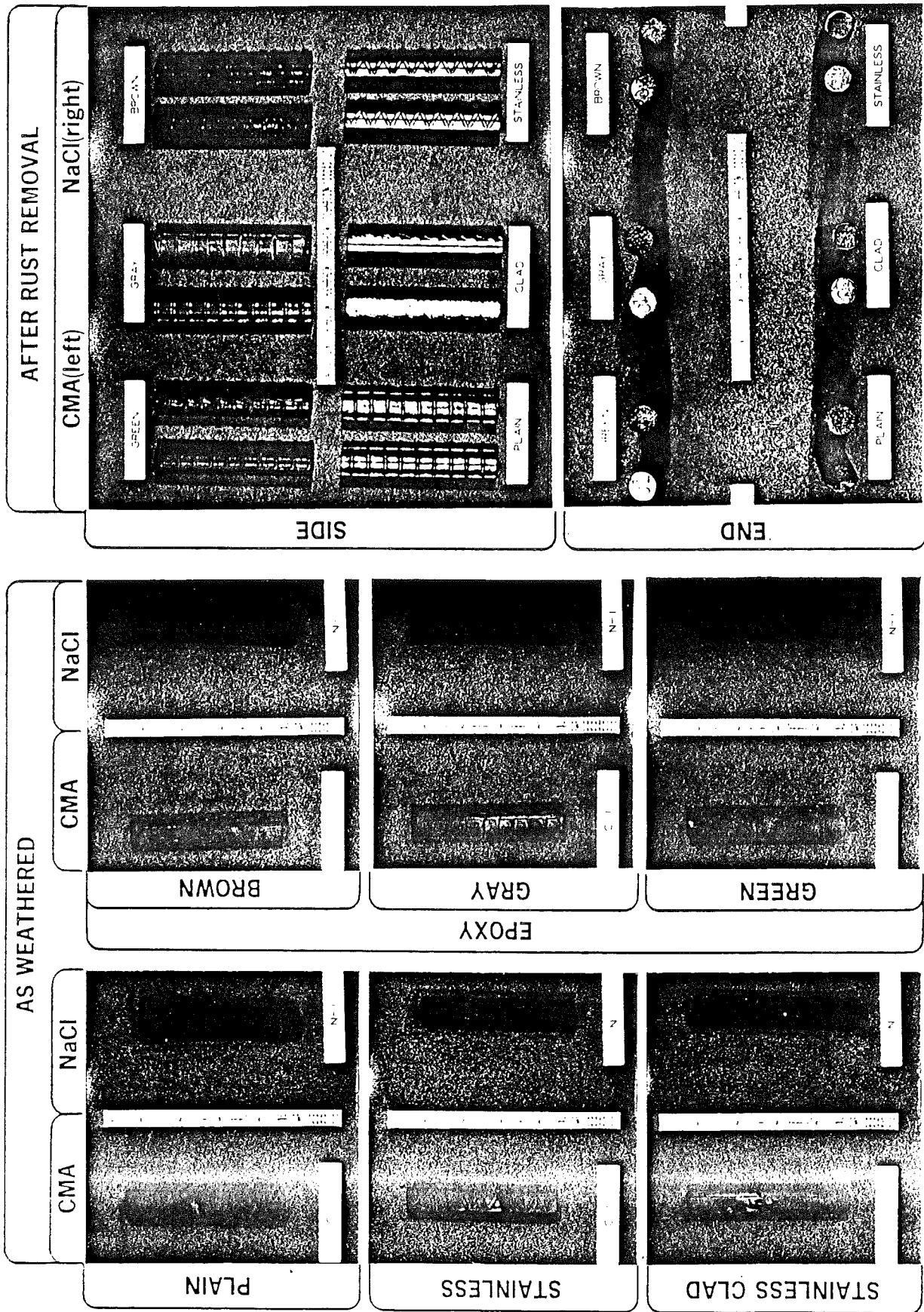


Figure 18. Bar reinforcement for concrete after three months exposure.

Thus, relative differences observed between specimens are significant even though the absolute values may seem somewhat exaggerated. Some estimates of the actual time that would be required to reach a comparable final state of corrosion are included in Tables 1 and 2 for several different weathering environments. As may be seen from the tables, the weathering environment used resembles most closely the marine-beach environment.

Bridge Steels

ASTM A36 and A572 steels (used in Michigan bridges in the painted state only) performed similarly for both environments with corrosion in NaCl being approximately three and one-half times as bad as that in CMA. ASTM A 588 steel performed slightly better than the other bridge steels in CMA but was markedly worse in the NaCl. All of the so-called weathering steel applications (ASTM A588, weathering steel guardrail, and ASTM A588 with previous NaCl exposure) experienced approximately eight times as much average corrosion in the NaCl as in the CMA.

Pitting, in general, for the weathering steel was also visibly worse than for the other bridge steels in the NaCl environment. While the maximum (worst case) pit depths were in the 40 to 70 mil range for all of the bridge steels in NaCl, the deeper pits were considerably more numerous on the weathering steels and of narrower diameter for the same depths. The shape of the pits occurring in the A588 specimens is more conducive to producing higher stress concentrations under load, suggesting that this material (when weathered) may be more susceptible to the effects of fatigue loading.

While pitting in general was not nearly as deep for the CMA exposure, some differences between the weathering steel and the other bridge steels were noticeable. A588 generally showed considerably narrower pit diameters for the same pit depths. The A588 specimens also experienced noticeably more pitting on the sheltered side (face not directly exposed to light during rotation).

For both environments, A588 also experienced noticeably more severe crevice corrosion (i.e., metal ion concentration cell corrosion) around the nylon clamps that secured the specimen in place. All of the bridge steels experienced markedly worse crevice corrosion in the NaCl environment.

Originally the rotation of the specimens in the weathering chambers was intended to allow sufficient drying time between dunkings that all specimens would be undergoing wet-dry cycling. After somewhere between 1-1/2 and 2-1/2 months of exposure, however, the oxide build-up on many of the steel specimens in the NaCl environment became great enough that they remained wet for the complete cycle. While this constitutes a more severe environment than was originally planned for testing, it is not an unrealistic environment. Investigation of Michigan's weathering steel bridges has indicated that such pockets of moisture can exist for

long periods of time on some portions of a structure (e.g., lower web and flange of beams over traffic lanes and behind the link plates of cantilevered expansion joints) (3). Additionally, the pitting ratio (i.e., worst pit depth/average corrosion magnitude) of our worst actual environments has been found to be on the order of 3.5 which can be seen to be roughly equivalent to the values in Table 1.

Prestressing Strand

The major strand data are included in Table 4. The control specimens, being from the same original roll as all of the test specimens, should be representative of the original state of the strand specimens. All of the control and almost all of the CMA specimens that were loaded to ultimate failure broke in the grips and undoubtedly the true ultimate tensile strengths would have been greater. The uncertainty in these values is expressed in the tables by the use of inequality symbols where appropriate.

The most significant result is the low ultimate strength of the NaCl weathered specimen. After three months, the value for one of the specimens is below 70 percent of the ultimate tensile strength (28,900 lb), a normal working load, and the other is only marginally above it. After six months, both specimens were below 70 percent of ultimate strength with one of the specimens being just barely above 50 percent. While some losses in strength appear to have occurred for the CMA specimens, they are much smaller and are of approximately the same magnitude for both the three and six-month specimens.

Surface appearance of the NaCl specimens is also much worse. After three months, pitting approached up to 40 percent (≈ 70 mils) of the initial individual wire diameter (165 mils) and up to 65 percent (≈ 100 mils) after six months.

Pitting for these specimens is, in general, present almost exclusively on the outer surfaces of the outer wires of the strands with the central wire experiencing only minor corrosion. The major corrosion occurring in this instance appears to be a form of crevice corrosion known as a metal ion concentration cell. For this type of cell, corrosion occurs primarily exterior to the crevices formed between adjacent surfaces. The primary driving force for this corrosion reaction is the difference in metal ion concentration that occurs between the crevice interior and its surroundings. This type of corrosion reaction normally progresses until the corrosion products exterior to the crevice have equalized the metal ion concentrations. A washing/wetting cycle that removes the soluble metal ions from the crevice surroundings starts the accelerated corrosion process all over again. Localized corrosion rates for such crevice accelerated reactions can be 10 to 100 times greater than would otherwise occur for comparable environments.

Such a situation may arise in actual service under any set of circumstances that allows deicing salt (NaCl) and water to gain access to the

steel strand. Contributors include cracks in the concrete, breaks in the plastic sheathing covering the strand, leaking anchorage plugs and bleed voids (Fig. 19) (4).

For the CMA exposure the tensioned strand performed essentially the same as the untensioned strand. While some small differences are shown in Table 4, these differences are on the same order of magnitude as the differences that occurred between the original control specimens.

For the NaCl exposure the tensioned strand performed markedly better with respect to both corrosion losses and ultimate strength losses than the untensioned strand. This is just the reverse of what would normally be expected. Apparently the built-in crevices within the strands are becoming effectively filled with corrosion products to the extent that they cannot accelerate corrosion as rapidly as initially. The differences between the tensioned and untensioned specimens are undoubtedly the indirect result of both the narrowing of the interwire spacing as the strand is loaded and the final tensile load state of the individual wires. The narrower spacing would allow the crevices to become filled sooner and the retained tensile load in the wires would make initial deformation of the wires by rust expansion forces more difficult. Other investigations have found that such crevice corrosion can continue operating although at a reduced rate as long as the crevice boundaries are not strong enough to prevent deformation by rust expansion forces (≥ 1200 lb/sq in.) (5).

While such crevice filling can slow this particular crevice corrosion reaction, it can only delay (and not stop) eventual strand failure. Even if the individual wires were initially stiff enough to prevent deformation, at some point in the corrosion process they will eventually be thin enough that they can no longer do so. The pit depths occurring suggests that such an eventuality would be more likely to happen sooner rather than later in a NaCl exposure.

Differences in the corrosion rates (Table 3) of the three and six-month specimens combined with the ultimate strength results (Table 4), suggest some other important differences between the CMA and NaCl exposures. While the strands exposed to CMA for six months showed essentially no change in ultimate strength from the three-month exposure batch, the corrosion loss measurements showed that they were continuing to corrode at close to the original three-month rate. Apparently corrosion had stopped (passivated) at the earlier sites and initiated at new ones. So even though metal loss continued, it occurred mostly at locations removed from the weakest areas left by the initial three months of exposure.

For the NaCl exposure, the situation appears to be just the opposite. The additional losses in strength that occur during the second three months appear to be directly related to the additional corrosion losses. In other words corrosion in the NaCl environment appears to continue essentially unabated in most of the original sites so that continued net section (strength) losses occur.

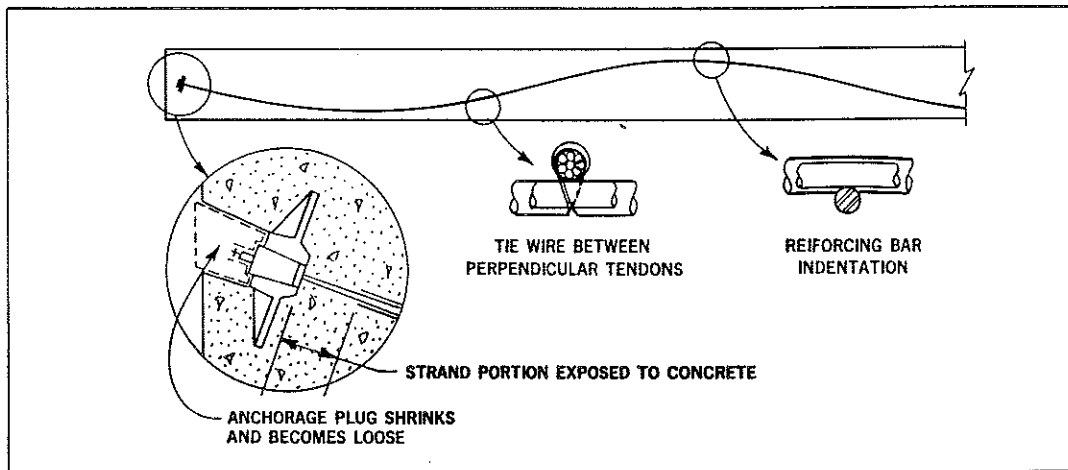
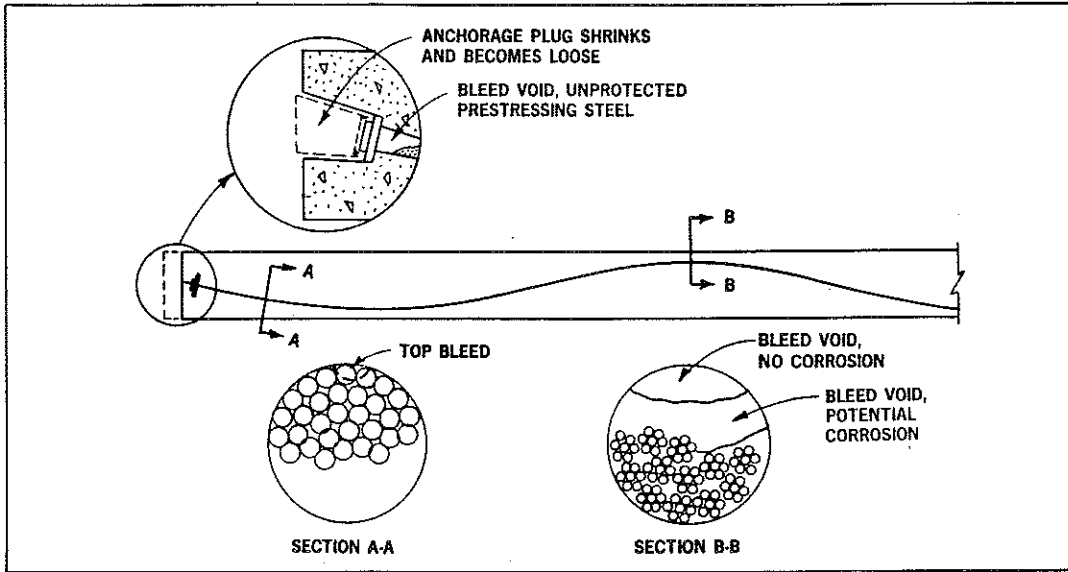


Figure 19. Conditions contributing to corrosion in post-tensioning tendons.

Of all the materials tested, the steel strand probably comes closest to being subjected to its own natural problem environment (i.e., dark, continually moist). Although the higher than normal service temperature as well as the more frequent periodic wetting will accelerate the weathering process to some extent beyond that of an actual environment, three months of tank weathering probably does not represent more than about two to four years of natural (worst case) environmental weathering.

Galvanizing

Significant performance differences were evident for the galvanized specimens. While performance was approximately uniform for all of the specimens exposed to NaCl, very noticeable differences were present among the CMA exposed specimens. As a result, the loss of galvanizing in the CMA environment varied from being one-third to only one-ninth as great as in the NaCl environment. The large differences in performance that were evident for the CMA exposed specimens suggest that potential differences in the galvanizing process may exist which could significantly (and favorably) affect the life of galvanized materials in a CMA environment.

Aluminum

All aluminum specimens performed extremely well in both environments. The average corrosion in both environments was negligible, but some mild pitting did occur on all of the NaCl exposed specimens (Figs. 15 and 17). The pitting (5 to 10 mils) was not of sufficient density or magnitude to result in any significant loss of strength but might act enough as a stress riser under tensile loading to adversely affect fatigue performance.

Reinforcing Steel for Concrete

Plain - Corrosion was noticeably worse in the NaCl environment. Performance in NaCl was intermediate between that of the weathering steel and the other bridge steels.

Epoxy Coated - Neither environment appeared to cause any damage to the epoxy coatings per se, but some corrosion did occur for the NaCl exposure at the unprotected cut ends. Rust undercutting of the epoxy had progressed to 1/4 in. from the ends for all three of the epoxy coatings tested.

Stainless and Stainless Clad - No noticeable corrosion occurred for the solid stainless rebar for either environment. Corrosion did occur for the stainless clad at the freely exposed cut ends where the ordinary steel core is exposed. Corrosive attack progressed to the extent of 5 to 15 mils for the CMA specimens and 30 to 60 mils for the NaCl specimens, on the exposed ends.

Painted Steels

Painted specimens are not scheduled for removal until after six and twelve months of exposure and will be evaluated then.

Galvanic Couples

Stainless/Galvanized - The galvanizing and underlying steel bolts proved to be especially sacrificial to the stainless nuts for both environments (Fig. 16). Although the NaCl exposure was apparently worse, this couple (for the ratio of sacrificial metal to protected metal as it exists here) would not be recommended for either environment.

Stainless/Aluminum and Galvanized Steel/Aluminum - These couples will both be evaluated after six and twelve months of exposure.

CONCLUSIONS AND RECOMMENDATIONS

CMA does appear to be considerably less corrosive than NaCl. For most materials tested the average corrosion losses in CMA were only one-third to one-tenth of those occurring in NaCl. Initial results also suggest that materials exposed to CMA probably experience more uniform pitting and, consequently, smaller reductions in the original strength. NaCl also appears to be more prone to creating deep narrow pits that are more likely to create stress concentrations that will adversely affect fatigue performance.

The corrosion evidence presently available suggests that CMA should be given much more serious consideration as a potential deicing agent (provided of course that CMA does function adequately as a deicing agent and it does not result in concrete deterioration, subjects of independent MDOT studies). The question still remaining to be answered is whether or not CMA can be cost competitive. The quantitative data that have been gathered in the present study provide a starting point from which such a determination can be more intelligently made.

While CMA is initially more expensive, potential savings can be derived from both decreased maintenance and increased service life for both highway structures and user vehicles. Total statewide usage may never be economically feasible, but limited usage may very well be practical in areas with:

- 1) High densities of structures subject to NaCl enhanced corrosion damage (i.e., urban areas with depressed freeways and their numerous overhead bridges, especially unpainted weathering steel bridges).

- 2) Individual irreplaceable structures especially susceptible to NaCl corrosion damage (i.e., cast concrete structures with steel strand tendons,

APPENDIX

Chemical Analysis of Deicing Salts

	CMA*	
	Mean, Percent	Standard Deviation, Percent
Acetate	72.4	± 3.5
Calcium	11.8	.8
Magnesium	8.9	.6
Water Insoluble	2.4	1.8
Moisture	1.3	.5
Chloride	.4	.1

	NaCl
	Percent
Sodium Chloride	98.06
Water Insoluble	1.04
Calcium Sulfate	0.63
Moisture	0.16
Calcium Chloride	0.05
Magnesium Chloride	0.05

*Analysis of CMA 'produced for field tests' furnished by FHWA