GALVANIZED STEEL REINFORCED CONCRETE BRIDGE DECKS

Progress Report

MICHIGAN DEPARTMENT OF STATE HIGHWAYS AND TRANSPORTATION

GALVANIZED STEEL REINFORCED CONCRETE BRIDGE DECKS

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Progress Report on a Highway Planning and Research
Investigation Conducted in Cooperation with the
U. S. Department of Transportation,
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Research Laboratory Section
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Research Project 68 F-103
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SUMMARY AND CONCLUSIONS

The specimens involved in this project are beginning to deteriorate, but many of them are still in relatively good condition. The results reported here are interim, and future developments may alter them to some extent. From the present condition of the specimens and the trends that are developing, it is expected that future changes will be a matter of degree, rather than of major consequence.

Based on the information presently available from the experiment, the following conclusions seem to be warranted.

Field Exposure Specimens (3-ft x 4-ft x 7-1/2-in. with typical bridge deck reinforcement, half of the bars galvanized in top mat only)

1) All of the typical types of bridge deck deterioration, viz., cracking, hollow area (delamination), and spalling , have been generated in the field exposure specimens by the action of salt and weather; without any live load or any significant dead load stresses.

2) While it is obvious that galvanizing does not prevent the occurrence of cracking, spalling, and hollow areas; serious deterioration is significantly less on the sections with galvanized bars.

3) Neither improved concrete mix nor galvanized rebars will provide long term durability if concrete cover is slight. One-half inch cover obviously is disastrous, and while 1-1/4 or 2 in. is better, it is not enough for structures that will be salted. Based on the results of this study, at least 3 in. of high quality concrete cover are recommended for decks subjected to deicing salts.

4) Salt content, electrical potential measurements, and corroding rebar all confirm the severe corrosive environment at the bar level of most specimens.

5) The ability of concrete to provide greatly improved protection when depth of cover is increased to 3 in. or more is evident from the simulated deck section. It also seems evident that the poorest portion of concrete is that part near the surface; and that the effects of placement and finishing greatly amplify that poor condition when a rebar is placed near the surface.

6) No significant adverse effects could be noted, where galvanized and ungalvanized bars were placed in direct contact in the concrete.

Experimental Bridge Decks

1) No early adverse effects have been noted due to mixing galvanized and uncoated bars in the top mat of one portion of an experimental deck. Certainly this is not recommended, but there appears to be no highly accelerated effect of such action.

2) All five experimental bridge decks with galvanized rebar in the top mat only over approximately one-half of each structure, are in excellent condition after four winters in the Detroit metropolitan area.

3) The feasibility of the use of galvanized bars in Michigan bridge deck construction has been demonstrated.

INTRODUCTION

This project was initiated in 1969, as a cooperative study with the Federal Highway Administration, under the Highway Planning and Research Program. It includes construction of laboratory specimens and experimental bridge decks for the evaluation of galvanized reinforcement as a deterrent to bridge deck deterioration. The project is being done in accordance with the research proposal dated May 1969.

Severe deck deterioration, in areas where deicing salts are used, caused the initiation of numerous investigations into methods of delaying such deterioration. Early investigators found that reinforcing steel in porous or cracked concrete contaminated with chlorides is susceptible to corrosion, and that advanced corrosion causes spalling of adjacent concrete. Professors B. Bresler and I. Cornet at the University of California at Berkeley, conducted experiments with the relative corrosion rates of galvanized and plain rebars in small laboratory specimens. They reported considerable reductions in the rate of corrosion for galvanized bars, and bond performance equal to or better than similar black bars.

This project was proposed to extend the investigation to larger simulated deck sections and full scale bridge decks. Construction of the field exposure specimens and the five experimental bridge decks, was discussed in Research Report R-845[1].

The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Several inert coatings have been developed in the past few years that were not generally available for use at the time that this project was initiated. Evaluation of epoxy coated rebars in comparison with galvanized and uncoated rebars is now under way at this Laboratory under a separate HP&R project that began in 1973. A recent report covers the general field of deck performance along with a review of the use of coated rebars[2].

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[1] Arnold, C. J., "Galvanized Steel Reinforced Concrete Bridge Decks, Construction Report," Michigan Department of State Highways and Transportation, Research Report No. R-845, January 1973.

[2] Arnold, C. J., "Bridge Decks in Michigan: A Summary of Research and Performance," Michigan Department of State Highways and Transportation, Paper prepared for the Conference on a Federally Coordinated Program for Research and Development at Pennsylvania State University, September 1976.

During the past year, publication of experimental results concerning galvanized reinforcement by the California Department of Transportation, has led to a new look at the subject. Subsequent action by the FHWA to limit further use of galvanized reinforcement in bridge decks has generated considerable controversy throughout the country. Since there is renewed interest in experimental projects dealing with galvanizing of reinforcement, this report has been prepared to show the present condition of the field exposure specimens included in this project, after six winters of treatment with salt and water.

Background

Since the publication of the hypothesis of the formation of fracture plane deterioration by Missouri State Highway Researchers in the mid-1960's, many people have accepted the fact that rebar corrosion is a major factor in deck deterioration. More recently, however, there seems to be less mention of the "failure plane," or "plane of weakness" along which fluids travel and failure progresses. Recent improvements in mix design and quality control of concrete have reduced the probability of formation of such planes in new decks. However, continued care and further improvements in these factors, as well as better construction techniques, are required along with the coated rebars if we are to achieve the goal of decks that perform well over the life of the bridge.

Another factor that is not widely mentioned is that the use of any finishing equipment on a deck surface generates a fluid wave in the concrete, so that it rises ahead of the float, depresses beneath the float, and rises again behind the float. If there are rebars near the surface, this action tends to segregate coarse aggregates from the area directly above the bar, leave the area above the bar slightly depressed, and increase the effective water/cement ratio of that small area so that shrinkage is higher than in the surrounding deck. These factors, along with the stress concentration caused by the presence of the bar, greatly increase the probability of vertical cracking directly above the bar. Bars buried more deeply below the surface, (perhaps 2-1/2 to 3 in.) do not cause this problem to occur to any great extent.

Therefore, in the newly proposed two-course construction, where cover over the rebars has been reduced in the first course, there will be an increased tendency for vertical cracking directly over the top rebars, in the first course. (Two course construction involves building a reinforced structural deck, followed by a bonded overlay of latex modified concrete or low water/cement ratio concrete such as the so-called 'Iowa' mix.)

Objectives

The objectives of the study were stated in the proposal as follows:

1) To determine the feasibility of using galvanized reinforcement in Michigan bridge deck construction.

2) To evaluate the effect of galvanized reinforcement on the performance of laboratory specimens and full-scale experimental bridge decks.

Scope

Twenty-nine 3 ft by 4 ft by 7-1/2 in. slabs were cast in the laboratory, for field exposure and periodic treatment with salt and water. Along with these slabs, a simulated composite deck section, 30 ft long, 56 in. wide and 7-1/2 in. thick was cast on a 36-in. wide-flanged beam. Concrete mixes for the laboratory specimens consisted of 6 and 7-1/2 sacks of cement per cubic yard, with 4-1/2, 5-1/4 and 6 gallons of water per sack of cement. Concrete cover over the bars varied from 1/2 to 2 in. in the laboratory specimens and 1/2 to 3-1/2 in. in the simulated deck. Typical deck reinforcement was included in the specimens and one-half of the steel in the top mat was galvanized. Weekly applications of water and salt are made during winter weather (December through March). Water is ponded on top of the specimens so that a concentrated solution of sodium chloride is present much of the time during the winter. Excess salt is washed from the surface each spring.

Five experimental bridge decks were built, with galvanized steel in the top mat on approximately one half of each deck.

EXPERIMENTAL DETAILS

Annual evaluations of the slabs include inspection for visible indications of deterioration, such as vertical cracking over the reinforcement and rust staining, along with soundings for delamination. Corrosion cell readings have also been made.

Specifications for galvanizing on the field exposure specimens called for 1-1/2 oz/sq ft average, with a minimum of 1 oz/sq ft. Measurements were made on the bars before and after galvanizing to check the actual thickness of coating applied. A total of 274 locations were checked. The

TABLE 1
CORROSION CELL READINGS, EXPERIMENTAL DECKS

Structure	Galvanized Sections						Non-Galvanized Sections					
	Distance From Curb						Distance From Curb					
Year of Readings	1 ft		6 ft		11 ft		1 ft		6 ft		11 ft	
	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.
Hubbell St												
1973	0.03	0.04	0.03	0.03	0.03	0.03	-0.08	0.04	-0.08	0.03	-0.08	0.03
1974	0.08	0.04	0.11	0.06	0.15	0.04	0.05	0.04	0.08	0.06	0.11	0.04
1975	0.17	0.08	0.19	0.07	0.21	0.08	0.13	0.08	0.11	0.08	0.12	0.06
1976	0.15	0.10	0.16	0.05	0.15	0.04	0.17	0.08	0.11	0.06	0.07	0.04
Schaefer Rd												
1972	0.15	0.04	0.15	0.03	0.20	0.05	0.23	0.04	0.21	0.03	0.26	0.05
1973	0.20	0.05	0.22	0.04	0.24	0.05	0.25	0.04	0.25	0.04	0.28	0.05
1974	0.21	0.05	0.26	0.04	0.26	0.04	0.25	0.06	0.28	0.06	0.29	0.06
1975	0.27	0.04	0.26	0.11	0.26	0.13	0.23	0.08	0.19	0.06	0.20	0.07
1976	0.26	0.07	0.21	0.06	0.21	0.04	0.25	0.06	0.22	0.06	0.22	0.05
Meyers St												
1972	0.57	0.10	0.50	0.08	0.54	0.12	0.38	0.05	0.33	0.04	0.36	0.06
1973	0.23	0.05	0.25	0.05	0.26	0.04	0.31	0.04	0.31	0.02	0.33	0.03
1974	0.22	0.06	0.22	0.04	0.23	0.04	0.34	0.05	0.32	0.05	0.34	0.07
1975	0.20	0.08	0.20	0.07	0.20	0.07	0.23	0.05	0.21	0.04	0.21	0.04
1976	0.25	0.09	0.24	0.08	0.27	0.08	0.35	0.11	0.32	0.09	0.31	0.09
Wyoming Ave												
1972	0.17	0.05	0.16	0.05	0.15	0.04	0.12	0.04	0.11	0.04	0.11	0.05
1973	0.12	0.05	0.14	0.05	0.13	0.04	0.11	0.07	0.14	0.07	0.15	0.06
1974	0.19	0.05	0.16	0.05	0.16	0.05	0.18	0.07	0.17	0.06	0.16	0.07
1975	0.19	0.04	0.16	0.06	0.14	0.06	0.18	0.08	0.15	0.07	0.13	0.09
1976	0.34	0.09	0.32	0.08	0.30	0.10	0.24	0.06	0.22	0.06	0.21	0.07
	3 ft		8 ft		13 ft		3 ft		8 ft		13 ft	
Grand River Ave												
1972	0.45	0.15	0.41	0.09	0.47	0.13	0.31	0.06	0.31	0.05	0.33	0.05
1973	0.23	0.05	0.24	0.03	0.24	0.03	0.29	0.04	0.31	0.04	0.31	0.03
1974	0.29	0.06	0.24	0.04	0.25	0.04	0.40	0.09	0.32	0.06	0.40	0.09
1975	0.30	0.07	0.26	0.07	0.26	0.08	0.35	0.11	0.28	0.10	0.28	0.10
1976	0.34	0.08	0.26	0.06	0.26	0.06	0.32	0.06	0.26	0.06	0.25	0.06

Note: First set of readings in each case is on the new deck. Readings made on 5 ft centers.

average coating thickness was 2.6 oz/sq ft, with a range from 0.6 to 5.9 oz/sq ft. Only one location measured 0.6 and the 5.9 reading occurred twice in the 274 points.

The second phase of the project involved the placement of galvanized rebar in the top mat only, on approximately one-half of each of five new bridge decks. These structures were placed in the Metropolitan (Detroit) District, in order to subject them to maximum traffic and deicing chemicals. The experimental bridges carry Hubbell, Schaefer, Grand River, Meyers, and Wyoming Streets over the new I 96 freeway. Contracts for the five structures included 205,976 lb of galvanized rebar at $.30/lb and 769,754 lb of ungalvanized rebar at $.19 to $.22/lb. The jobs were let in 1971 and the decks were built in 1972.

Specifications for coatings on the structures required galvanizing in accordance with ASTM A 123, with the exception that the weight of coating average no less than 1-1/2 oz/sq ft with no individual specimen less than 1 oz/sq ft. Test results from rebars checked, showed coating thicknesses ranging from 2.8 to 4.4 and averaging about 3 oz/sq ft.

Details of the construction are published in Research Report R-845. It was found during construction that the contractor had placed alternate ungalvanized bars among galvanized bars in the top mat in a negative moment area of one of the structures. Since no additional galvanized bars were available, they were left in place.

Yearly surveys, including visual condition checks, corrosion cell readings and delamination-detector runs are made on the experimental decks. Corrosion cell readings have been generally low with a few isolated higher readings near the expansion dams (Table 1).

Evaluation

Early evaluations of the field exposure specimens revealed that salt had penetrated to the top layer of steel and some rusting of ungalvanized bars had occurred during the first winter of treatment.

Table 2 shows a summary of the electrical potential measurements from the field exposure slabs. Such readings have been recorded periodically on these specimens, and also have been made on numerous bridge decks throughout the State. The values are noted for long-term trends in evaluation of experimental decks or specimens, but are not weighted heavily in conclusion, because of the wide variability in readings that occurs and because they give no indication of the extent or severity of the corrosion.

TABLE 2
ELECTRICAL POTENTIAL MEASUREMENTS

Galvanized Rebar Experimental Slabs

Concrete Cover	Sacks/ cu yd	W.C. Ratio (gal/sack)	Galvanized Bars (Average)						Plain Bars (Average)					
			6/71	7/72	8/73	8/74	9/75	8/76	6/71	7/72	8/73	8/74	9/75	8/76
1/2-in.	6	5-1/4	0.74		0.52	0.63	0.55	0.43	0.56		0.56	0.59	0.55	0.44
	6[2]	5-1/4	0.78		0.61	0.62	0.51	0.44	0.56		0.65	0.62	0.52	0.49
	6	6	0.78		0.56	0.60	0.55	0.52	0.58		0.58	0.56	0.53	0.54
	7-1/2	4-1/2	0.66		0.54	0.67	0.54	0.56	0.55		0.56	0.60	0.57	0.56
1-1/4-in.	6	5-1/4	0.56		0.54	0.59	0.55	0.47	0.50		0.50	0.43	0.52	0.51
	6[1]	5-1/4	0.71		0.56	0.58	0.54	0.46	0.50		0.48	0.51	0.55	0.46
	6	6	0.60		0.54	0.52	0.52	0.48	0.48		0.50	0.48	0.60	0.52
	7-1/2	4-1/2	0.45		0.50	0.45	0.36	0.44	0.38		0.46	0.41	0.46	0.52
2-in.	6	5-1/4	0.47		0.48	0.51	0.48	0.54	0.41		0.42	0.45	0.44	0.51
	6[2]	5-1/4	0.61		0.57	0.60	0.65	0.59	0.53		0.44	0.48	0.51	0.58
	6	6	0.55		0.47	0.49	0.51	0.46	0.49		0.42	0.47	0.52	0.49

Simulated Deck Section

Concrete Cover	Galvanized Bars (Average)						Plain Bars (Average)					
	6/71	7/72	8/73	8/74	9/75	8/76	6/71	7/72	8/73	8/74	9/75	8/76
1/2-in.	0.68	0.57	0.51	0.57	0.40	0.60	0.60	0.68	0.59	0.53	0.42	0.63
1/2-in.[2]	--	--	--	--	--	--	--	--	0.62	0.57	0.49	0.66
1-in.	0.59	0.62	0.52	0.50	0.48	0.48	0.51	0.57	0.54	0.52	0.39	0.54
1-1/2-in.	0.41	0.53	0.47	0.42	0.41	0.45	0.44	0.47	0.49	0.45	0.45	0.54
2-in.	0.27	0.36	0.40	0.34	0.35	0.38	0.31	0.42	0.41	0.36	0.36	0.40
2-1/2-in.	0.28	0.34	0.34	0.29	0.32	0.36	0.28	0.34	0.37	0.29	0.31	0.36
3-in.	0.30	0.37	0.38	0.30	0.31	0.37	0.27	0.34	0.34	0.29	0.31	0.36
3-1/2-in.	0.35	0.43	0.44	0.49	0.46	0.51	0.29	0.40	0.41	0.30	0.37	0.42

[1] Lapped bars.

Note: Specimens were cast in 1970, and had been salted for one winter before the introduction of the half-cell potential measuring device.

They are included here for the information of those interested in such values for comparison with other experiments in progress. The most recent results in the table show values well above the threshold for corrosion (approximately 0.35v), for the uncoated bars, in all the experimental slabs; and in all but the most deeply covered portions of the simulated deck.

Electrical potential measurements also have been made periodically on the experimental bridge decks in Detroit, and are shown in Table 1. The structures are approximately four years old, and are still in new condition. The relatively low readings on the uncoated bars indicate the probability that significant quantities of salt have not yet penetrated to the level of the steel.

While there is some controversy in the field concerning the meaning and practical usefulness of electrical potential measurements for uncoated steel bars, there is even less agreement concerning the meaning of similar readings for galvanized bars. The values were recorded at the suggestion of FHWA researchers involved in early use of the potential measurement device, and are included here for reference in case other researchers have interest. They do show the high potential generated by the sacrificial zinc coating in the salty concrete, and indicate the relative activity of the coating.

Photos in the Appendix of this report show the condition of the field exposure specimens, after six winters of heavy salt treatment. In each case, there are six No. 6 "transverse" bars and two No. 4 "longitudinal" bars in the top mat, with the No. 6 bars above the No. 4's. Three of the No. 6 bars are galvanized and three uncoated, while both of the No. 4's are galvanized. The figures are arranged so that the galvanized bars are in the right hand half of the slab. A typical bottom mat of six No. 6 "transverse" and four No. 5 "longitudinal" bars all uncoated, is included in each specimen. Dark stained areas of the surface are wet, because ponded water was swept off just before the pictures were taken.

During the summer of 1976, cores were removed from the field exposure specimens and the simulated deck section. Each core was cut at the junction of a No. 6 and a No. 4 bar in the top mat. The cores were cut into slices and crushed for salt analysis, and bars were removed for inspection. Salt analysis has been interrupted by higher priority work in the laboratory; therefore, the partial data available have not been included in this report. Preliminary data show the effect of improved concrete quality in reducing salt penetration. However, it is masked in part by increased penetration aided by cracking of the concrete caused by deteriorating bars near the surface.

RESULTS

Field Exposure Specimens

Performance information is limited to date, since many of the specimens are still in relatively good condition. Only a small amount of spalling and isolated hollow areas have occurred. All specimens had extensive hairline cracking over the bars at the end of three years. Rust staining occurred early in the uncoated bars with 1/2-in. cover. Open cracks, evidently due to expansion of corrosion products, have occurred earlier and more extensively on the plain bars with 1/2-in. cover. A hollow area of approximately 20 sq in. occurred first at four years of age in the 7-1/2-sack mix, plain bars, with 1/2-in. cover. The following year, a hollow area developed in the galvanized specimen with spliced bars, 6-sack mix and 1/2-in. cover. These areas have been cored. Figure 1 shows a slice of core containing a delamination adjacent to spliced, galvanized bars. This area extended for approximately 1 sq ft, and is the worst area in the galvanized specimens. The other delamination, although smaller in area, was similar in appearance. At the present time, there is a hollow area of about 12 sq in., in the specimen with spliced, uncoated, bars, 1/2-in. cover, 6-sack mix. Some evidence of the fracture plane is evident on the surface of the specimen. (See photo of specimen No. 21 in the Appendix.)

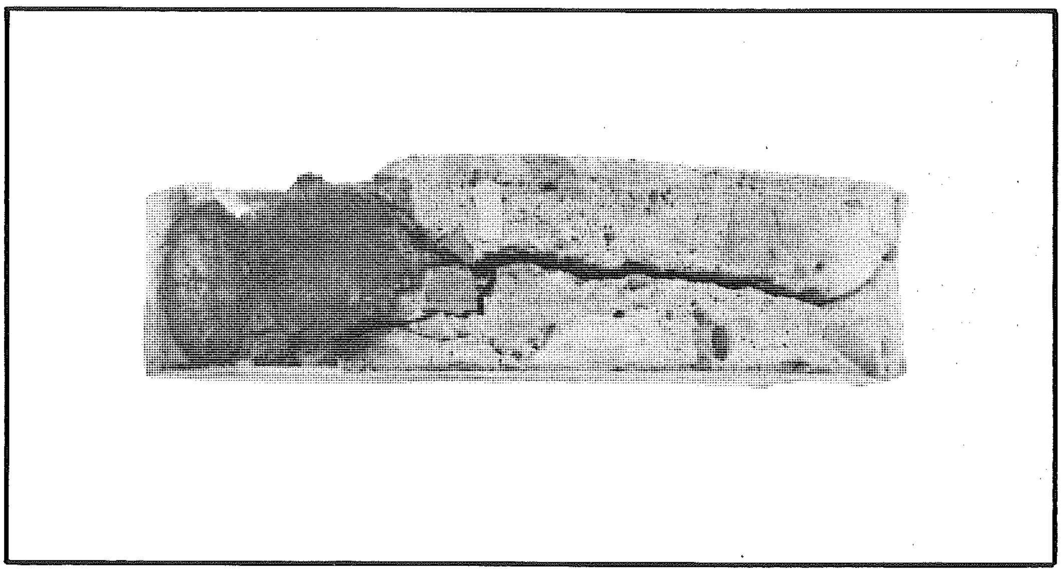

Figure 1. Core splice from block No. 5, showing delamination adjacent to spliced galvanized bars. Cover was 1/2-in. Hollow area was first noted during the 5-year inspection. It represents the worst deterioration to date of specimens with galvanizing. The top portion has not yet spalled away.

It is evident from the information gathered thus far that the galvanized portions of the specimens are in considerably better condition, on the average, than the uncoated portions. Some of the galvanized bars removed from the cores show loose white corrosion products on the surface. In other cases, the surface is so badly stained that it is difficult to determine the coated from the uncoated bars. However, a polished specimen shows that most of the coating remains on the bars in the stained areas.

It is difficult to effectively quantify the amount of deterioration in a concrete specimen or rebar. However, some form of measurement must be made in order to compare the various specimens that are included in the project. Table 3 shows the results of such an evaluation, with the rating system noted below the tabulated area. Here, another difficulty is obvious; that of comparing coated bars with uncoated bars. The original coating on the main cylindrical portion of the bars averaged approximately 0.005 in. thick and was less than 0.010 in. in all cases. Therefore, corrosion would have to penetrate the coating and into the bar, to have the sample rated '3' or more. Since the primary purpose of a coating is to protect the bar from attack, this rating system does not seem unreasonable. If, during corrosion of the coating, high pressures develop and damage the concrete, that will show up in the two right-hand columns of the table which relate to the condition of the specimens as a whole. Therefore, the rating systems shown in the table seem to be reasonable for the task at hand.

The ratings show better performance for the coated bars, which agrees with a subjective assessment of the appearance of the bars and specimens.

There has been controversy concerning the effect of mixing galvanized top mat with ungalvanized bottom mat in structural decks. The field exposure specimens on this project contained uncoated No. 6 bars in direct contact at right angles with the galvanized No. 4 bars underneath. Examination shows no visible penetration of the galvanized coating at the contact point on the galvanized No. 4 bars. In general, it was not possible visually to determine where the contact point had been, once the bars were separated.

While it is obvious that galvanizing does not <u>prevent</u> the occurrence of deterioration of the slabs, serious deterioration appears to be significantly less on the sections with galvanizing. The long term significance of the effect of galvanizing or whether the process is cost effective is not totally clear at present. The deleterious effects of the very small amount of concrete cover on some of the specimens are graphically illustrated by the results to date.

TABLE 3

RATING OF FIELD EXPOSURE SPECIMENS AND REBARS FROM CORES FALL 1976 (AFTER SIX WINTERS OF SALT TREATMENT)

Experimental Details			Bars From Cores Rating		Rating of Specimens			
					Plain Bars		Galvanized Bars	
Concrete Cover	Cement, sacks/cu yd	Water, gal/sack	Plain No. 6 Bars	Galvanized No. 6 Bars	Open Cracks, percent	Spalls, percent	Open Cracks, percent	Spalls, percent
1/2	6	5-1/4	4.0	2.0	78	29	16	7
	6*	5-1/4	3.7	2.1	62	19	17	4
	6	6	4.5	2.0	54	14	20	9
	7-1/2	4-1/2	2.6	2.1	42	7	0	0
1-1/4	6	5-1/4	3.3	1.2	6	0	0	0
	6*	5-1/4	3.5	1.4	24	2	9	0
	6	6	3.3	1.2	4	2	0	0
	7-1/2	4-1/2	1.5	1.0	0	0	0	0
2	6	5-1/4	2.8	1.0	0	0	0	0
	6*	5-1/4	3.3	1.0	6	0	16	0
	6	6	3.5	2.0	12	6	6	2
1/2	6*	5+	3.3	---	33	8	--	-
1/2	6	5+	4.0	2.0	5	7	0	5
1	6	5+	4.5	2.0	0	0	5	0
1-1/2	6	5+	3.8	1.5	0	0	0	0
2	6	5+	1.0	1.0	0	0	0	0
2-1/2	6	5+	1.0	1.0	0	0	0	0
3	6	5+	1.0	1.0	0	0	0	0
3-1/2	6	5+	1.0	1.0	0	0	0	0

* Bars Spliced

Rating system for bars is as follows:

1. No corrosion; possibly some bar discoloration.
2. Light corrosion; scattered but slight rusting with essentially no pitting.
3. Moderate corrosion; concentrated spotty pitting of the bar, up to 1/32-in. depth, over less than 1/2 of bar length.

3.5. As 3 above but more general over the bar length.

4. Heavy corrosion; concentrated pitting on one or more spots; deeper than 1/32-in., over less than 1/2 of bar length.

4.5. As 4 above, but more general coverage over the length of the bar.

Rating of the specimens in the field; cracking and spalling are listed as a percentage of the total length of No. 6 bar of the specified type, in the top mat. For example, cracking or spalling extending along 30 lin in. of uncoated bar, would be 30 percent of the 100 in. of uncoated bar in a given specimen.

Experimental Decks

The five experimental decks, now approximately four years old, are showing no signs of deterioration at this time. Evaluations are done each year, consisting of condition surveys, electrical potential measurements, and surface inspections with the delamination detector. These yearly inspections will continue in the future.

Continuation of the Project

The specimens and experimental decks of this research project will be evaluated for several years to come. It is not intended to issue another major report in the near future, but any significant developments will be published as they occur. No coring will be done on the experimental decks until there is some evidence of deterioration. In the interim period, information on the project may be obtained from this office.

TABLE A-1
EXPERIMENTAL DETAILS OF THE
LABORATORY SPECIMENS

Slab No.	Cover, in.	Bars Spliced	Concrete Design		Air Content, percent	Slump, in.	28-Day Compressive Strength, psi
			Cement, sacks/cu yd	Water, gal/sack			
1	1-1/4	No	7-1/2	4-1/2	5.4	2-3/8	5530
2	2	No	6	5-1/4	7.6	4-1/8	3760
3	1/2	No	7-1/2	4-1/2	5.7	3-1/2	4580
4	2	No	6	5-1/4	7.4	5-1/2	3810
5	1/2	Yes	6	5-1/4	5.5	3	4810
6	1-1/4	No	6	5-1/4	6.1	2-7/8	3310
7	1-1/4	No	6	6	5.6	7-1/2	3950
8	2	Yes	6	5-1/4	7.7	3-7/8	3440
9	2	Yes	6	5-1/4	7.5	4-1/2	4400
10	1/2	No	6	5-1/4	5.9	2-1/8	4080
11	1-1/4	Yes	6	5-1/4	6.7	3-1/2	4540
12	2	No	6	6	7.0	8-3/8	3420
13	1/2	No	7-1/2	4-1/2	5.3	1-7/8	5080
14	1/2	No	6	6	7.4	7-1/8	3960
15	1-1/4	No	6	5-1/4	4.1	1-1/2	4740
16	1/2	No	6	6	5.8	7	4200
17	1/2	No	6	5-1/4	5.1	2-1/8	4380
18	2	No	6	5-1/4	5.2	2-3/8	4520
19	1-1/4	No	6	6	4.8	7-1/8	3950
20	1-1/4	Yes	6	5-1/4	4.2	1-7/8	5140
21	1/2	Yes	6	5-1/4	5.9	4-1/4	4390
22	1-1/4	No	6	6	12.4	7-1/8	2650
Field Beam [1]							
Section							
30	1/2	Yes (3)	6	5+	5.8	5-1/4 [2]	2920
31	1	No	6	5+			
32	1-1/2	No	6	5+			
33	2	No	6	5+			
34	2-1/2	No	6	5+			
35	3	No	6	5+			
36	3-1/2	No	6	5+			

[1] Field Beam (4 ft, 7-1/2 in. by 36 ft by 7-1/2 in. on 36-in. WF 150 beam with shear developers).
[2] After 15 mile haul in ready mix truck.

APPENDIX

Since the use of galvanizing for bridge deck steel has become quite controversial in recent months, and because this research project is one of the very few conducted by a highway department, the following photos are included in this report for review by interested parties. The first series (Fig. A1) shows the condition of the field exposure specimens as they appeared during the summer of 1976, after six-winters of heavy salt treatment. Dark stained areas on the surfaces of the specimens are wet from ponded water that was swept from the specimens shortly before the pictures were taken.

It has been noted that cracks seem to form most easily over the outermost bars, evidently because of the closer proximity to the end of the block. These blocks have 4 in. of clearance from the centerline of the bar to the block end. Greater end clearance would seem to be desirable for future installations.

Table A-1 shows the variables for each specimen. Note that specimens 23 through 29 have not been included, since they did not contain comparative galvanized and uncoated bars.

Cores were cut from the second or 'middle' bar of each type, positioned so as to cut both that bar and one of the No. 4's. If significant differences in potential existed along the bar, the core was cut at the end with higher potential.

Some typical rebars from the cores were cut, polished, and etched to show the cross-section of the bar and coating. Bar samples were wire brushed to remove loose material, prior to cutting. The resulting cross-sections are shown in Figures A2 through A14. Due to the short time available for polishing, some details are not entirely clear. However, the views have been included to give a general idea of the condition of the coating in the various specimens.

In each case the dark mottled structure at the top is a plastic potting compound used to mount the specimen; the black line on some pictures is a gap where the plastic did not bond to the surface of the specimen; next comes the coating, and the lighter colored, etched steel is below. In general, the poorer side of the bar is shown. Reference can readily be made to the figure showing the general condition of the specimen from which the bar was taken. Please refer to Table 3 in the text, for definitions concerning the rating system used.

In the 3 ft by 4-ft specimens (1 through 22) where cover was 2 in. or less, and in the shallower cover portions of the simulated deck, galvanized bars were stained so darkly that their appearance was much like a gray steel rebar without coating. Only at the maximum covered parts of the simulated deck section was the traditional galvanized appearance evident. Many of the stained bars, however, had retained most of the coating thickness, and had not caused any ill effects on the concrete.

Salt content, electrical potential measurements, and corroding rebar all confirm the severe corrosive environment at the bar level of most specimens.

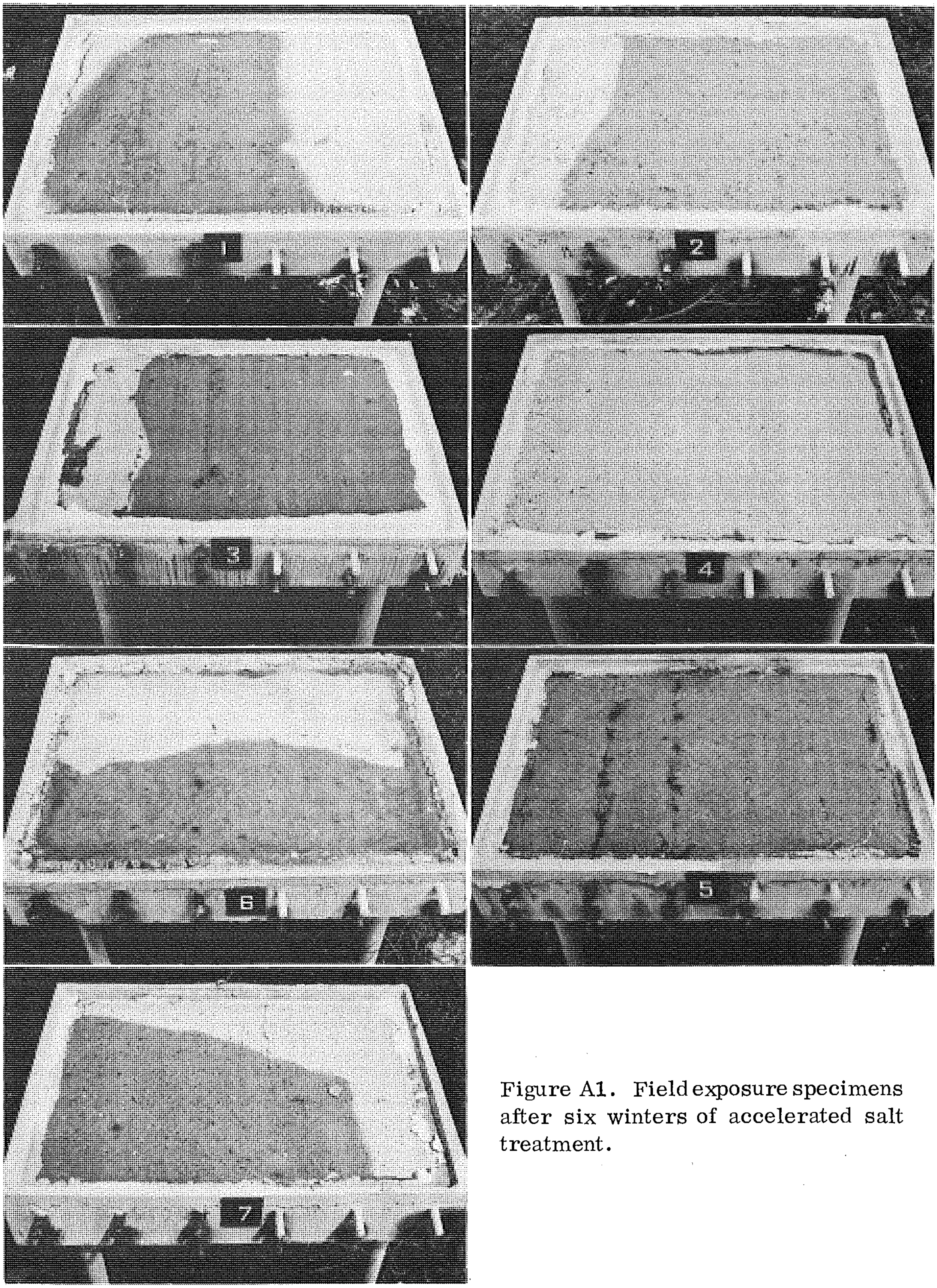

Figure A1. Field exposure specimens after six winters of accelerated salt treatment.

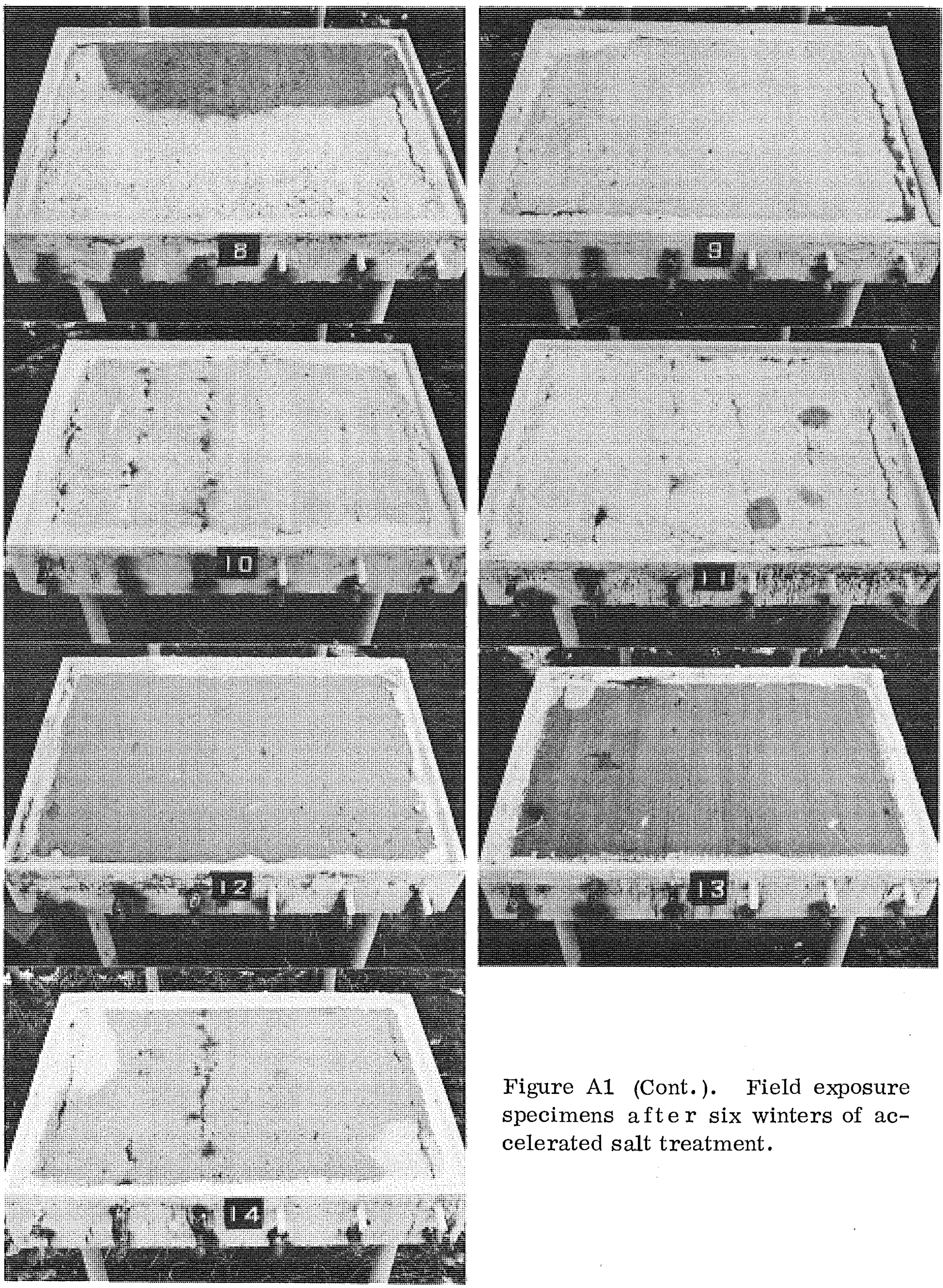

Figure A1 (Cont.). Field exposure specimens after six winters of accelerated salt treatment.

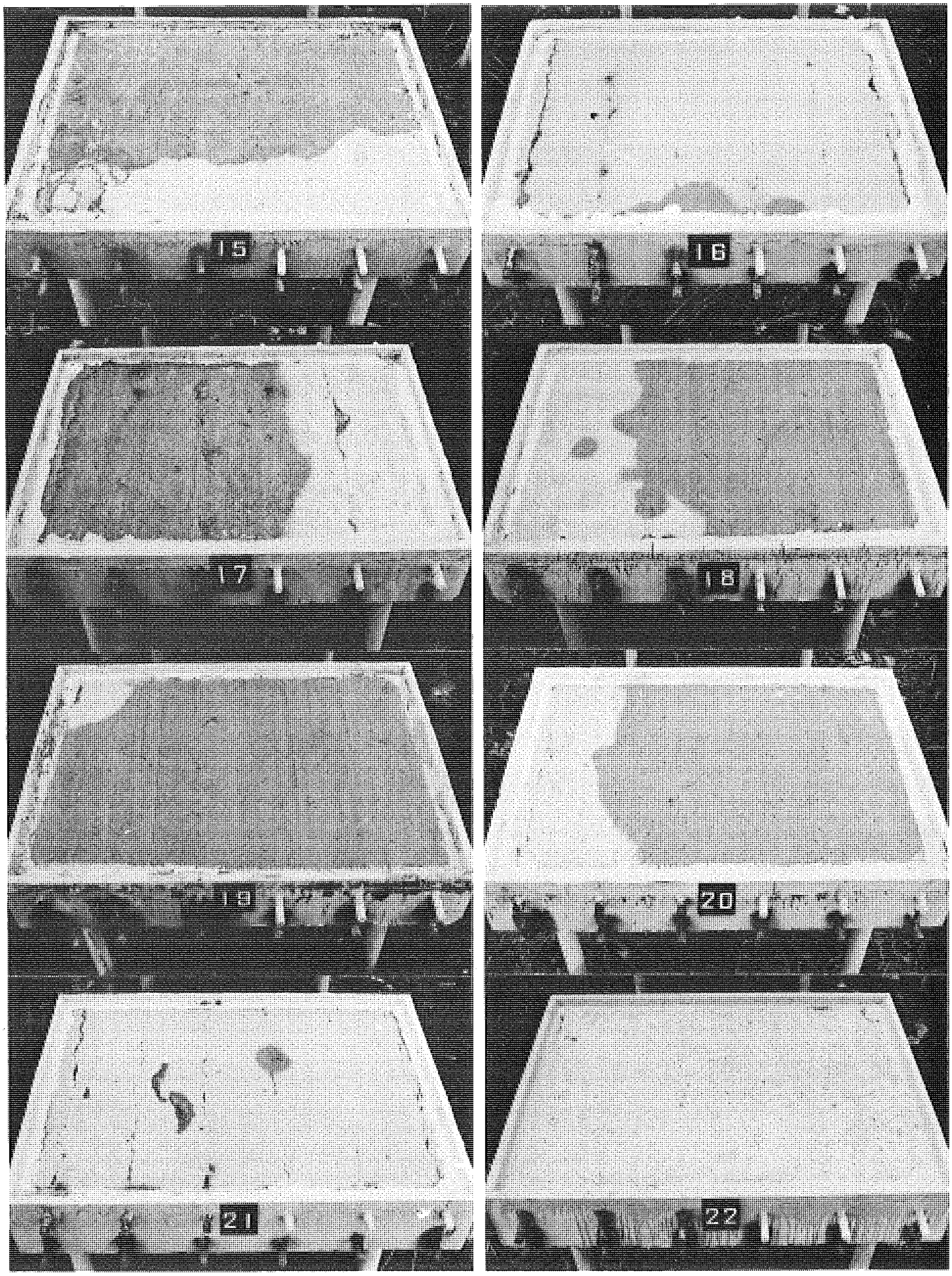

Figure A1 (Cont.). Field exposure specimens after six winters of accelerated salt treatment.

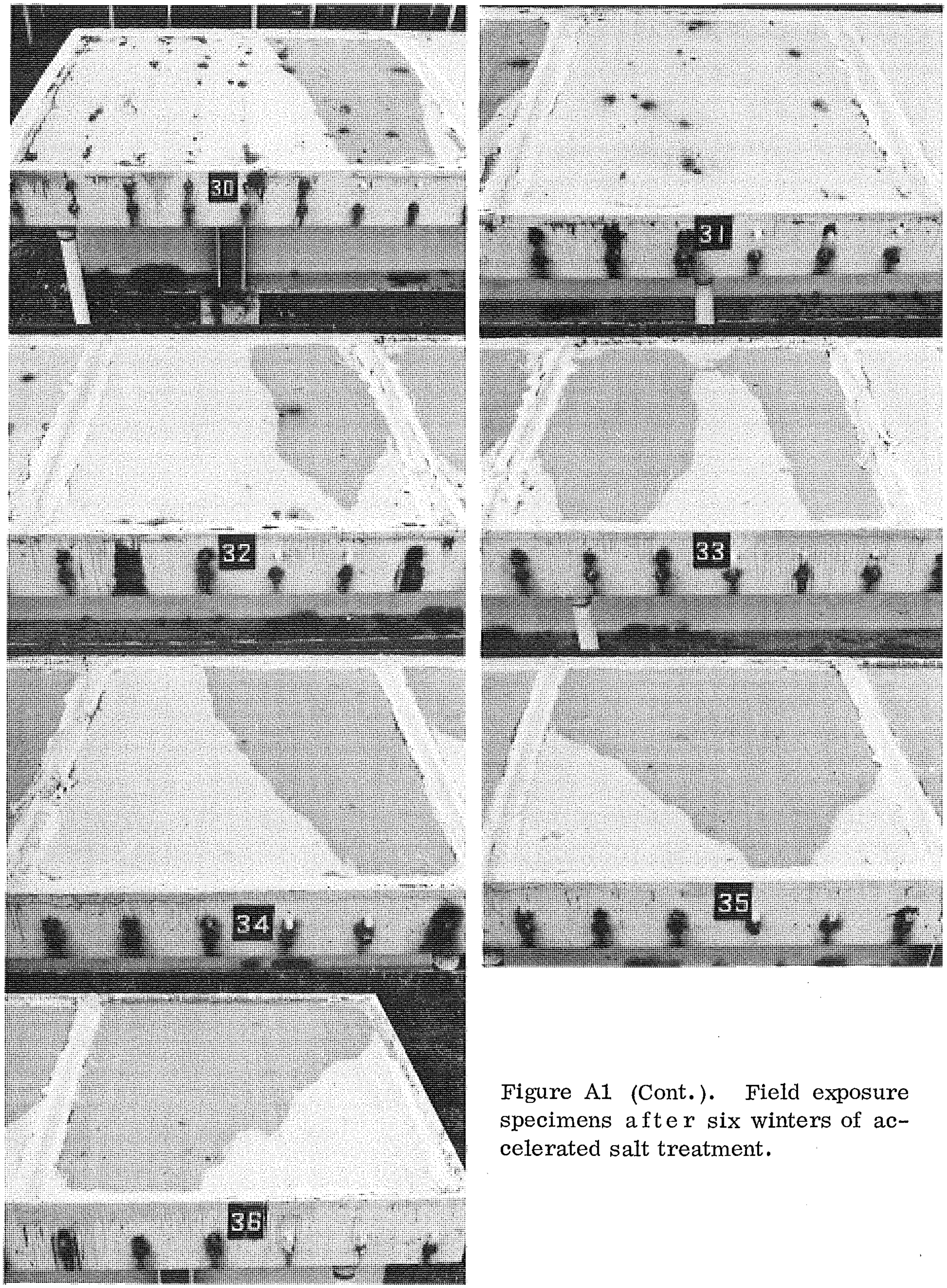

Figure A1 (Cont.). Field exposure specimens after six winters of accelerated salt treatment.

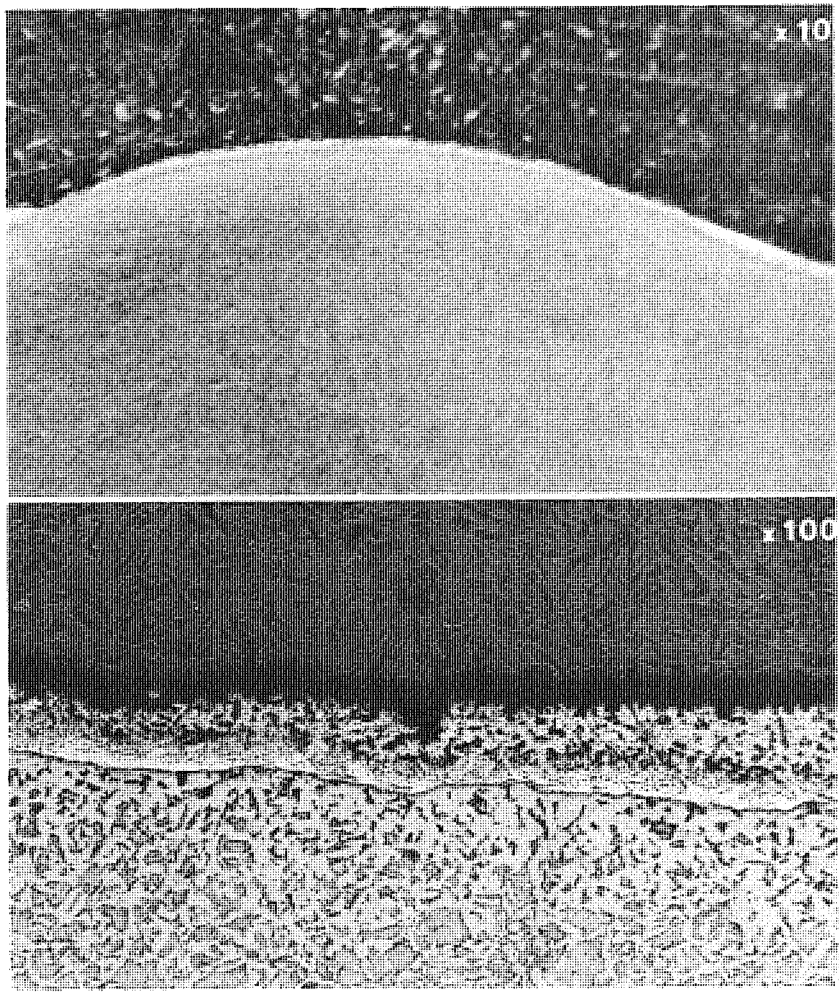

Figure A2. Section of stained galvanized bar from Specimen No. 1. Pictures taken at location of thinner coating. Other side of bar had heavier coating. (Concrete still in good condition: 1-1/4-in. cover; 7-1/2 sack, 4-1/2 gal/sack mix.) The comparable uncoated bar had scattered light rusting on one side.

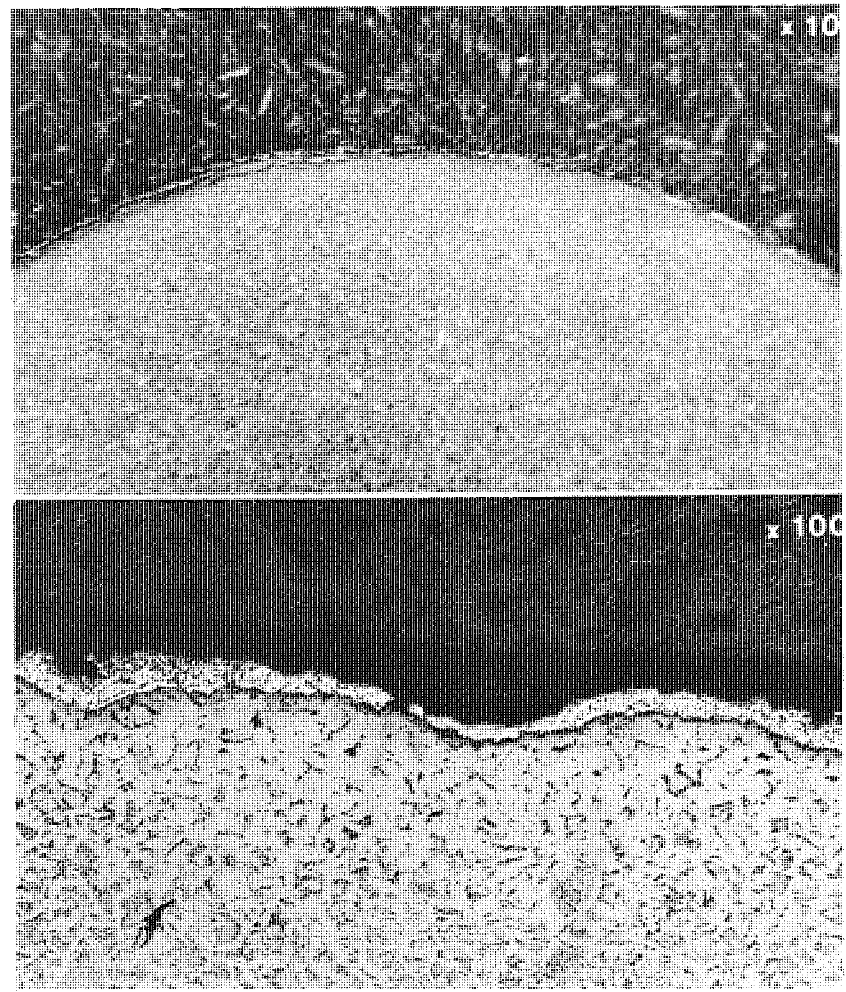

Figure A3. Galvanized bar from Specimen No. 2. Much of the coating gone, but bar protected from attack. (Concrete still in good condition: 2-in. concrete cover, 6 sack, 5-1/4 gal/sack mix.) The comparable uncoated bar had moderate corrosion on one side and heavy corrosion with pitting over most of the other side.

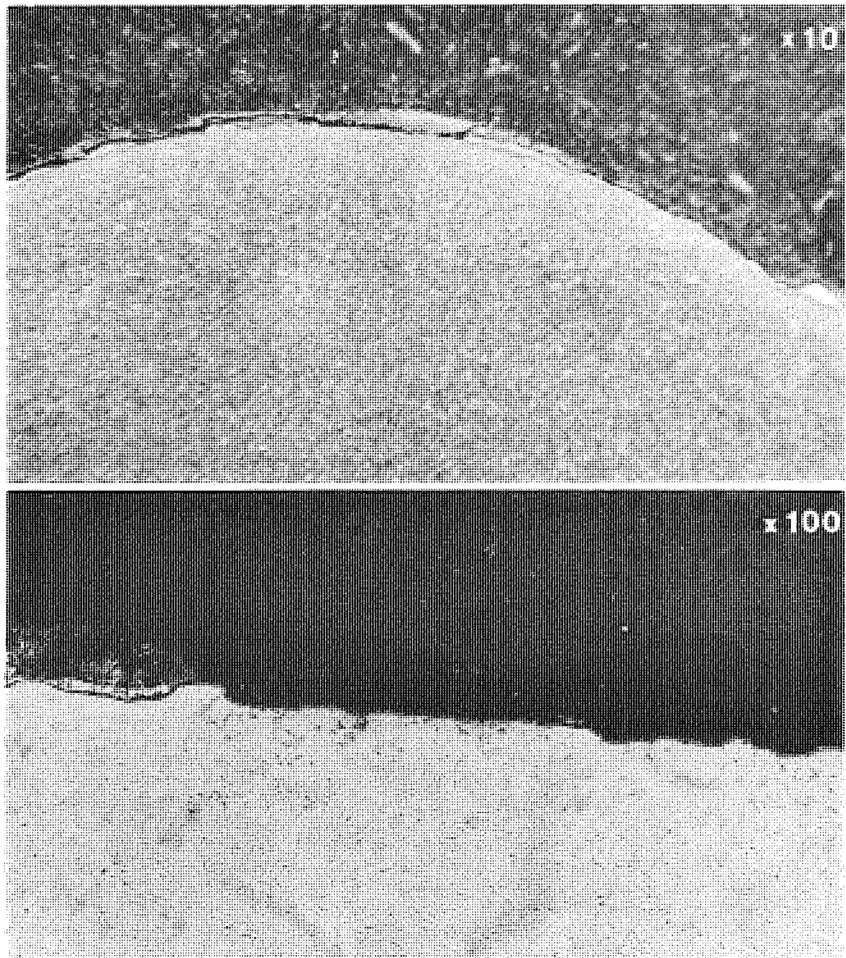

Figure A4. Galvanized bars from Specimen No. 3. Much of coating gone, but only scattered and slight rusting on the bar. (Concrete in good condition above galvanized bars, but showing distress over uncoated bars: 1/2-in. cover, 7-1/2 sack, 4-1/2 gal/sack mix.) The comparable uncoated bar had scattered light rusting on one side and heavy corrosion with pitting over most of the other side.

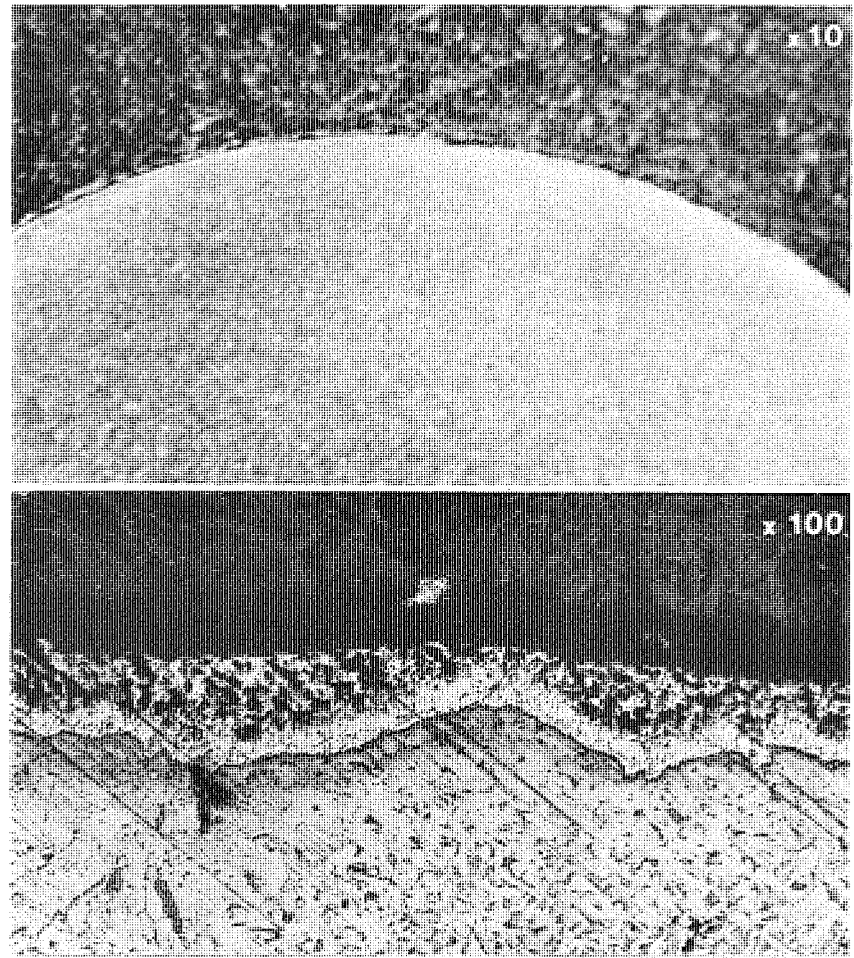

Figure A5. Galvanized bar from Specimen No. 4. Slight attack on coating. (Concrete still in good condition: 2-in. cover, 6 sack, 5-1/4 gal/sack mix). The comparable uncoated bar had moderate corrosion on one side, and heavy corrosion with pitting over most of the other side.

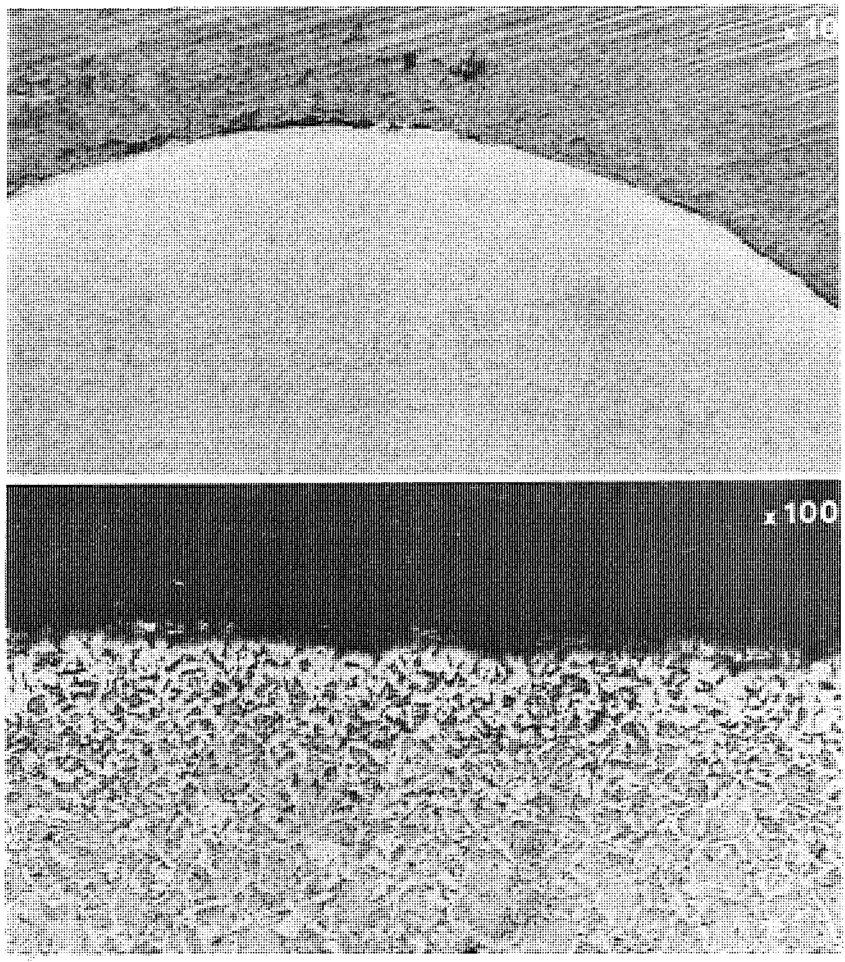

Figure A6(a). Galvanized bar from hollow area on Specimen No. 5. Most of coating gone from some parts on this side of bar. Moderate spotty corrosion of bar. Other side of bar in better condition and adjacent (splice) bar was also in relatively good condition. (Concrete showing signs of distress above uncoated bars, looked good but had hollow area in galvanized section: 1/2-in. cover, 6 sack, 5-1/4 gal/sack mix.)

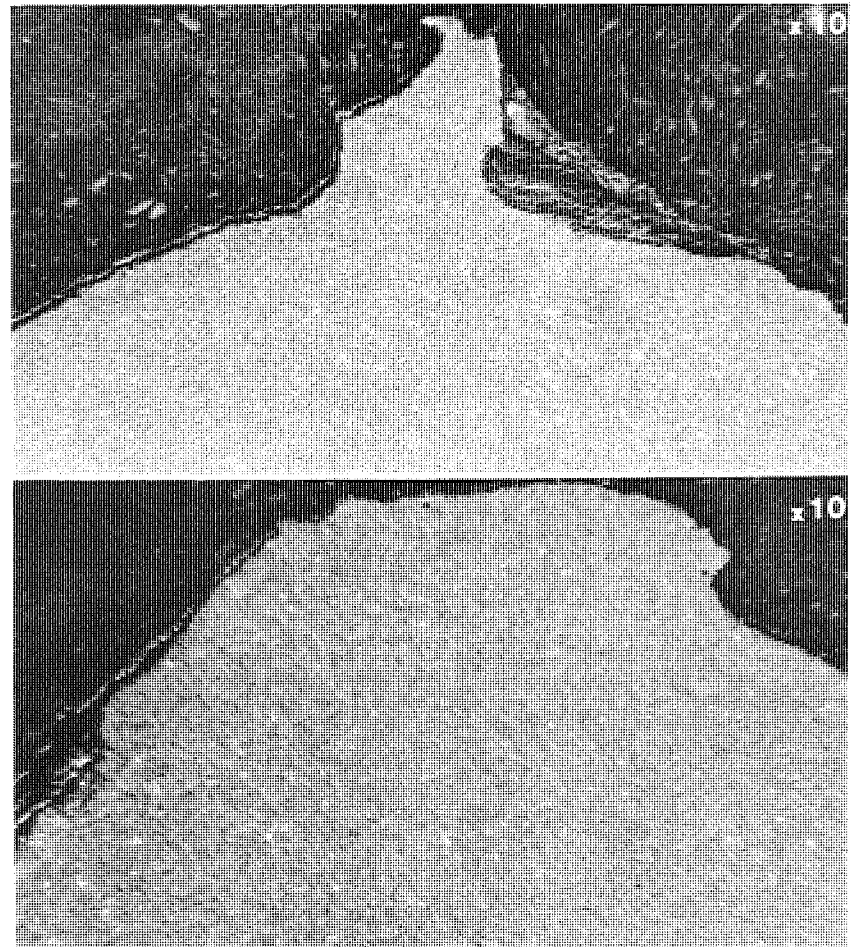

Figure A6(b). Cross-sections of uncoated bars from Specimen No. 5 showing deterioration of rib (above) and general corrosion (below). The uncoated bars varied from light corrosion on one side of one bar, to heavy corrosion over most of the remainder of that bar and both sides of the adjacent (splice) bar.

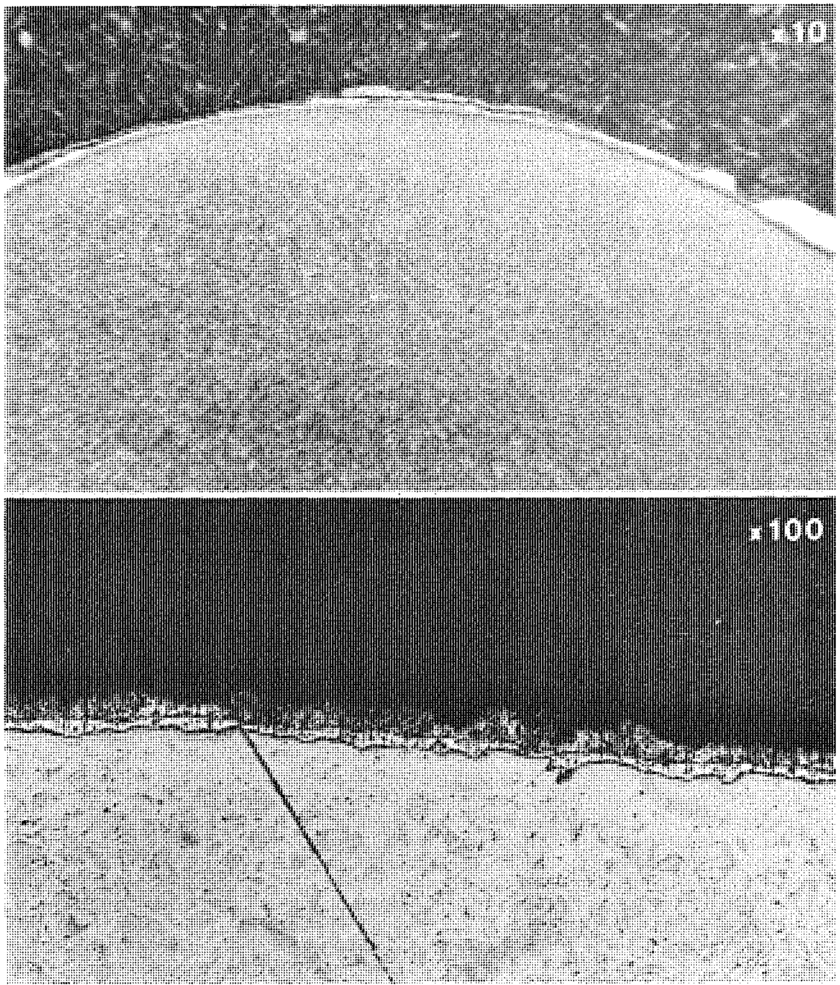

Figure A7. Galvanized bar from Specimen No. 8. Some corrosion of coating evident, but no penetration of the coating. Uncoated bar had light to moderate corrosion (2-in. cover, 6 sack, 5-1/4 gal/sack mix, spliced bars).

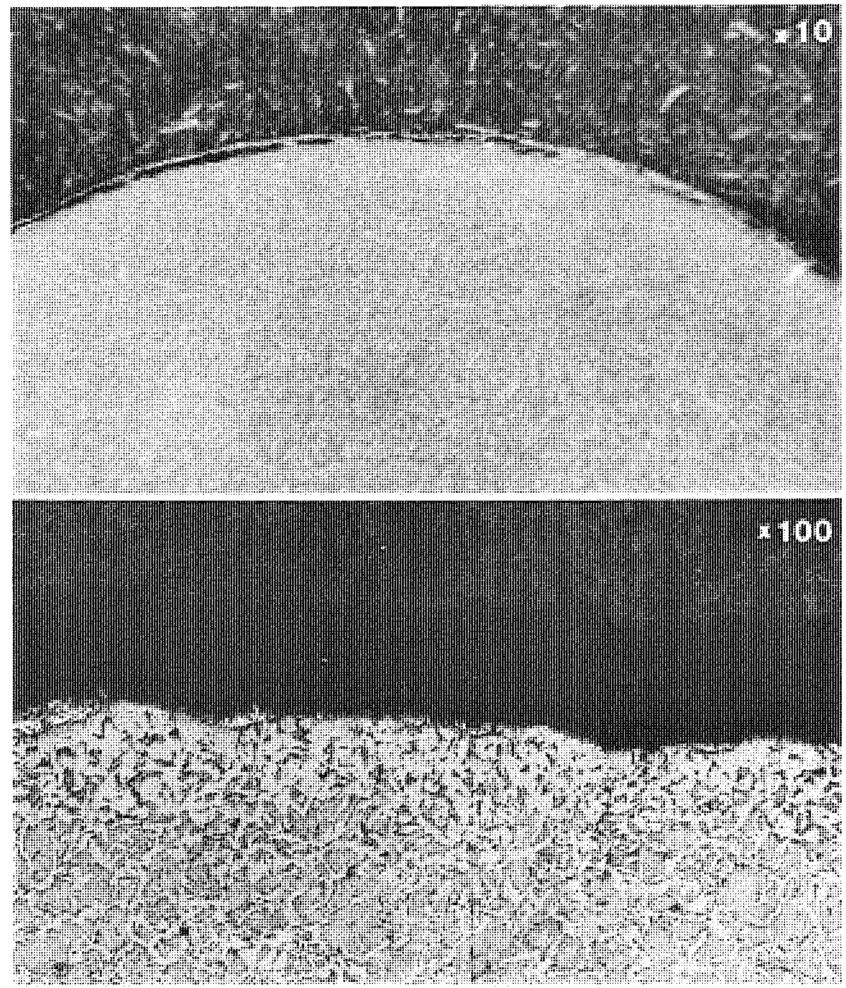

Figure A8. Galvanized bar from Specimen No. 10. Coating is nearly gone, and the concrete above the coated bars has begun to crack, but is still in better condition than the concrete over the uncoated bars (1/2-in. cover, 6 sack, 5-1/4 gal/sack mix). The comparable uncoated bar had moderate corrosion over most of one side and heavy corrosion with pitting on most of the other side.

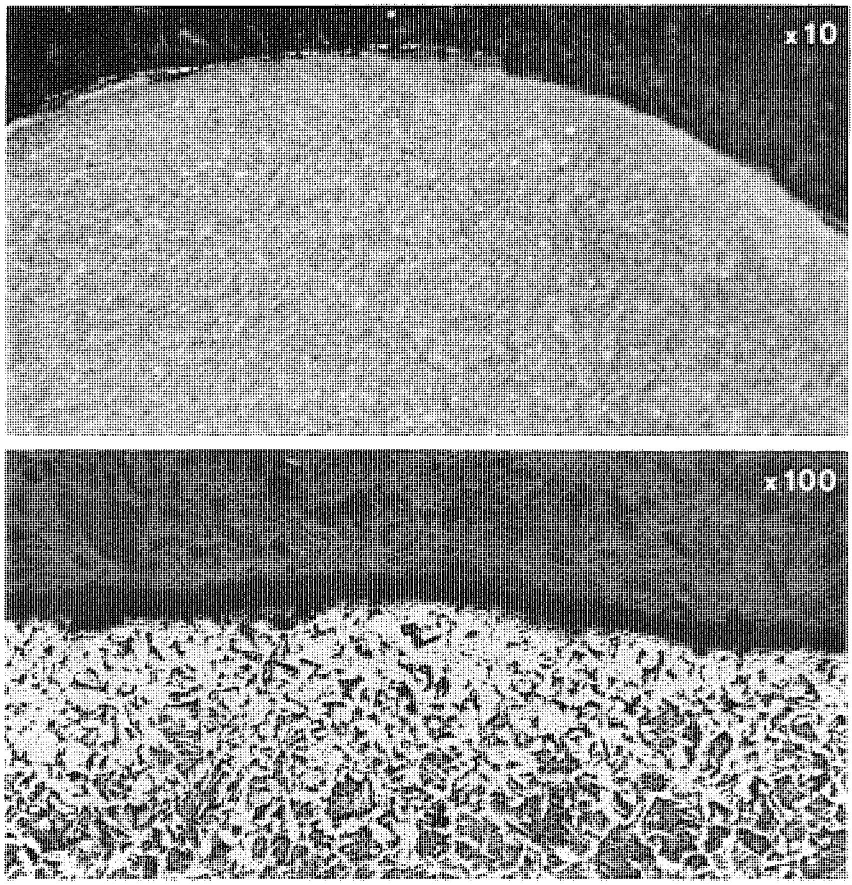

Figure A9. Galvanized bar from Specimen No. 11, which has a considerable amount of cracking on both the galvanized and uncoated sections. (The photo of Specimen No. 11 exaggerates the severity of cracking on the galvanized side, because that side was not yet quite as dry as the other side: 1-1/4-in. cover, 6 sack, 5-1/4 gal/sack mix). The other (splice) galvanized bar was in better condition. One of the comparable uncoated bars had scattered light rusting on both sides and the other had heavy corrosion and pitting on part of one side and most of the opposite side.

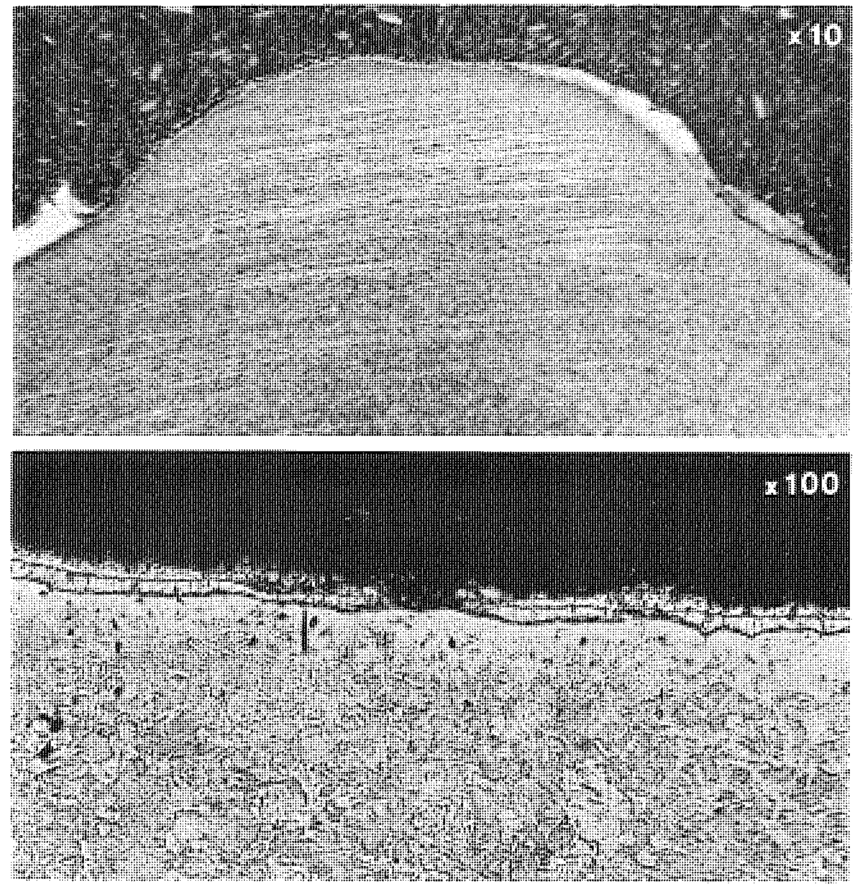

Figure A10. Galvanized bar from Specimen No. 12. Much of the coating is gone from the bar and light corrosion is evident on both sides of the bar. Bar has been protected by the coating (2-in. cover, 6 sack, 6 gal/sack mix). Comparable uncoated bar had moderate corrosion on part of one side and heavy corrosion on part of the other side.

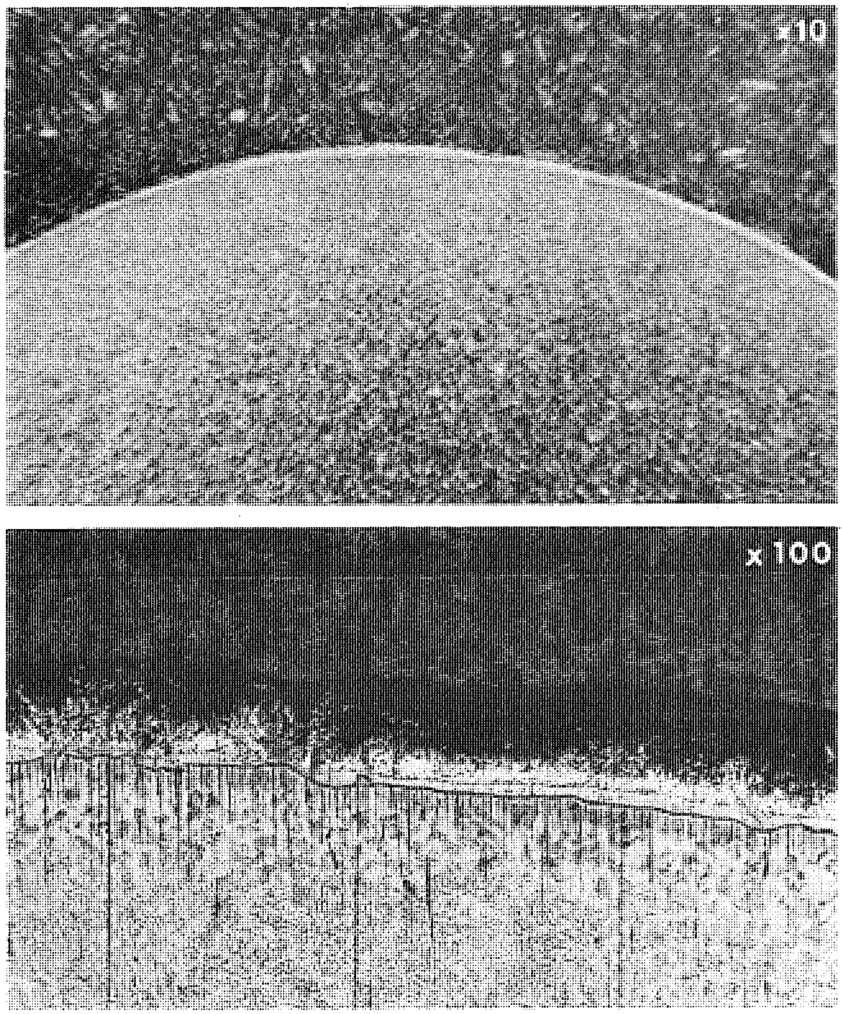

Figure A11. Galvanized bar from Specimen No. 15. Coating stained, but in good condition on both sides of bar. Concrete in good condition over entire specimen (1-1/4-in. cover, 6 sack, 5-1/4 gal/sack mix). Comparable uncoated bar had moderate corrosion on part of one side and heavy corrosion on most of the other side.

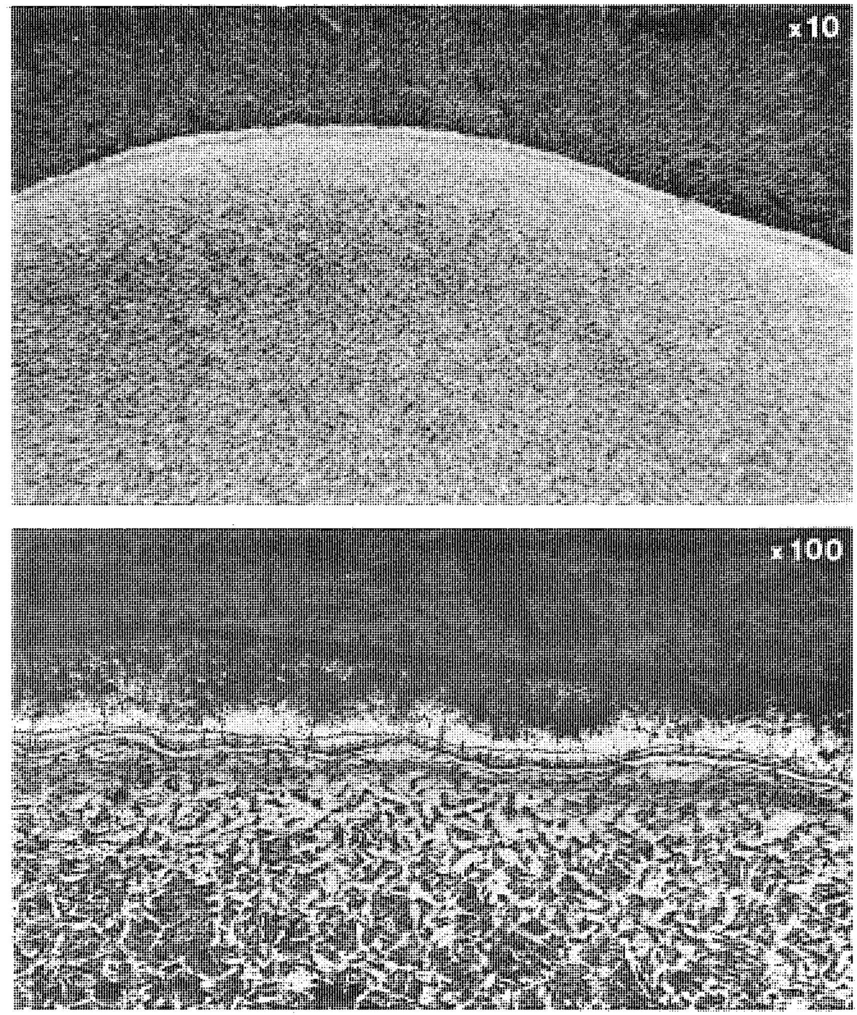

Figure A12. Galvanized bar from Specimen No. 18. Coating and concrete both in very good condition (2-in. cover, 6 sack, 5-1/4 gal/sack mix). Comparable uncoated bar also was uncorroded.

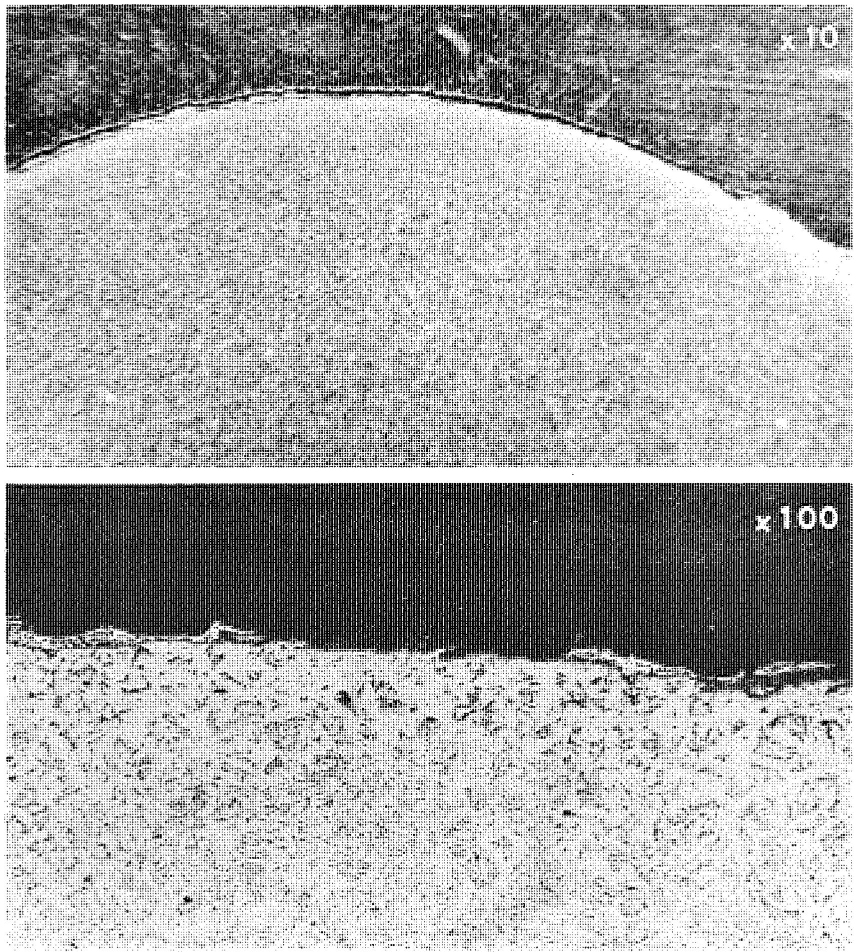

Figure A13. Galvanized bar from Specimen No. 19. Much of the coating is gone from this side of the bar but bar was protected. The other side is still very good and looks much like Figure 12. Concrete still in good condition (1-1/4 in. cover, 6 sack, 6 gal/sack, mix). Comparable uncoated bar had heavy corrosion over most of both sides.

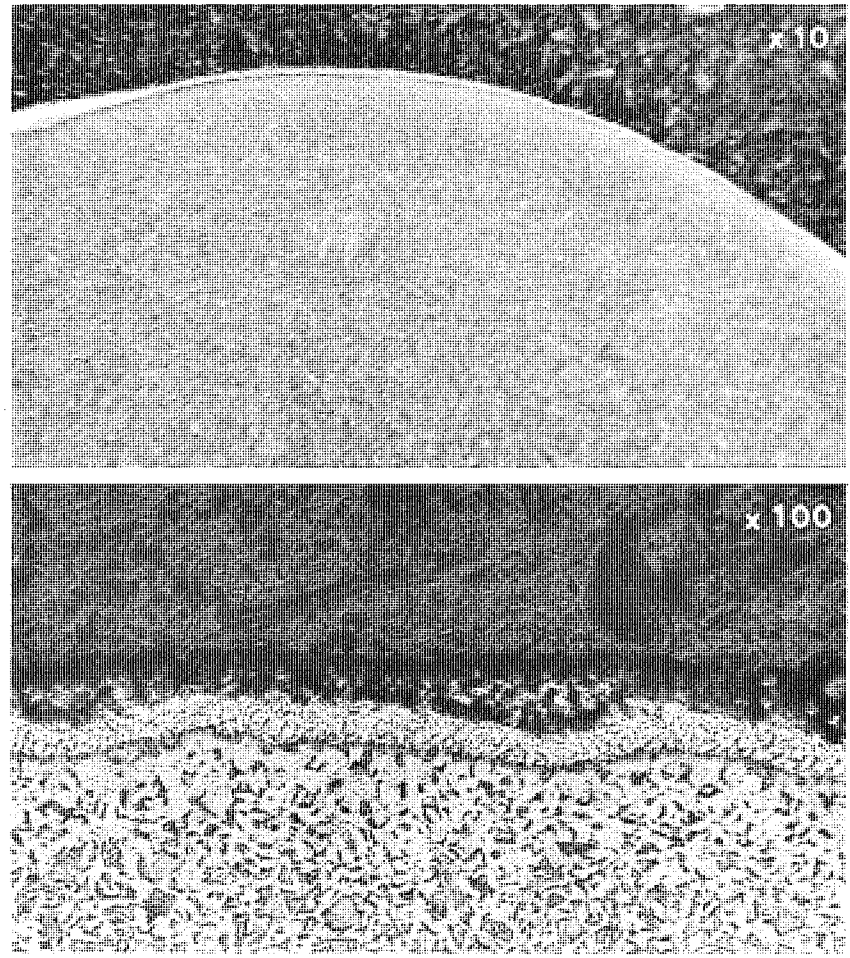

Figure A14. Galvanized bar from Specimen No. 35. Coating in virtually new condition. Only those at these maximum cover depths have maintained the shiny galvanized appearance. (There, as in some other cases, the corner of the coating has been rounded by the polishing and etching procedures.) Concrete in very good condition (3-in. cover, 6 sack, 5+ gal/sack mix). Comparable uncoated bars also were in excellent condition.