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16. ABSTRACT

This is meant to be a final report of one phase of the research on protective coatings for structural steel bridges along the coastal areas of California. At the requests of the Bridge and Materials & Research Departments, funds were made available for this work in 1952. A major portion of the allotment was used to place about a half-dozen different paint formulations in about 48 different combinations on Leffingwell Creek Bridge No. 49-44, located on Road V-SLO-56-B.

The compositions and combinations used were listed and described in detail in the report dated October 14, 1952, prepared by Paul Jurach of the Bridge Department. The compositions were devised and designed by E.D. Botts of the Materials & Research Department. The combinations were worked out in collaboration with Dale F. Downing of the Bridge Department. A supplemental report and comment on the

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Bridge Painting

STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

FINAL REPORT

on

PROTECTIVE COATINGS USED IN THE EXPERIMENTAL PAINTING of the LEFFINGWELL CREEK BRIDGE

59-20

January, 1959

MATERIALS & RESEARCH DEPARTMENT

State of California
Department of Public Works
Division of Highways
Materials and Research Department

January 30, 1959

V-SLO-56-B
Work Order #13NN57

Mr. F. W. Panhorst
Assistant State Highway Engineer
California Division of Highways
Sacramento, California

Dear Sir:

Submitted for your consideration is:

FINAL REPORT

on

PROTECTIVE COATINGS USED IN THE

EXPERIMENTAL PAINTING

of the

LEFFINGWELL CREEK BRIDGE

Study made by.........................Technical Section
Under general direction of...........Bailey Tremper
Work supervised by...................E. D. Botts
Report prepared by...................E. D. Botts

Very truly yours,

F. N. Hveem
Materials & Research Engr.

cc: JWTrask
MHarris
PJurach
AMNash
DDowning

EXPERIMENTAL PAINTING OF LEFFINGWELL CREEK BRIDGE

Final Report

This is meant to be a final report of one phase of the research on protective coatings for structural steel bridges along the coastal areas of California. At the requests of the Bridge and Materials & Research Departments, funds were made available for this work in 1952. A major portion of the allotment was used to place about a half-dozen different paint formulations in about 48 different combinations on Leffingwell Creek Bridge No. 49-44, located on Road V-SLO-56-B.

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[illegible] the capacity of the bridge [illegible]

[illegible] funds were made available [illegible]

[illegible] portion of the bill [illegible] was used [illegible]

[illegible] current traffic conditions [illegible]

[illegible] Phelps-Dodge Bridge [illegible]

[illegible] 50-5 [illegible]

[illegible] and comparisons [illegible]

[illegible] October [illegible]

[illegible] Bridge Department. The conditions [illegible]

[illegible] the materials [illegible]

[illegible] deterioration [illegible]

[illegible] Bridge Department [illegible]

[illegible] December [illegible]

[illegible] and [illegible]

Department. Cursory reports were issued by the Bridge Department in September 1953 and June 1954. A detailed evaluation was made by Botts of Materials & Research and Jurach of Bridge in July 1955, each working independently. The quantitative evaluation was issued at that time in conjunction with a progress report by Botts of the date August 16, 1955. That report, except that it contained extensive references to further experiments on San Simeon and other bridges, could well serve as a major part of this report and interested readers are referred to the progress report of August 16, 1955. The three years that have passed since that time have, as predicted, merely accented the features observed in July 1955 and recorded in the progress report. As could be expected, the "accenting" of the features has not been uniform. Generally speaking, the failing coatings noted in 1954 and 1955 had progressed toward total failure much more rapidly than those coatings showing good resistance to corrosion. Nevertheless, the spread between values assigned in 1955 and those assigned in 1958, while not uniform, are generally of the same order of magnitude. The evaluations referred to, of course, are from one source only. Several people have made quantitative evaluations independently, and though the values selected by them are generally of the same order, the probability of consistency is greater when values all come from one source.

The final data on all individual panels of the bridge are presented herewith in pictorial form. The legends appearing above the panels on the overhanging deck indicate the location of the

panels on the bridge, the type of paint applied, whether surface was treated or untreated and the number of coats of each kind of paint.

Legends:

The letter H refers to the panels on the south half of the bridge; N refers to the north half. All panels had been thoroughly sandblasted.

U	-	Untreated
T	-	Treated
Al	-	Aluminum Finish (State Specification 52-G-80)
VAl	-	Vinyl Aluminum (State Specification 53-G-49)
Str	-	Stringer
ZnCh	-	Zinc Chromate (State Specification 52-G-51)
VRL	-	Vinyl Red Lead
VERL	-	Vinyl Epoxy Red Lead
RLPh	-	Red Lead Phenolic
RL No. 3	-	Previous Standard Red Lead Primer No. 3
SQDRL	-	Semi-Quick Dry Red Lead (52-G-53 State Specification at present time)

Numbers preceding any of the symbols indicate the number of coats applied. Composition of the paints is given in the Appendix.

Figure No. 1 is a picture of Leffingwell Bridge in its entirety. The photographer, facing the bridge, was only a few feet from the surf line of the Pacific Ocean at the time the picture was taken. At the right is the southern approach; at the left the northern approach. The succeeding figures from Fig. 2 to Fig. 19 inclusive, encompass the entire span of the steel substructure supporting the

concrete deck of the bridge. There are occasional overlappings of panel sections in the sequence of photographs. Necessarily, the photographic record shows the western side of the I beam spans and, to a limited extent, the bottom flanges. As a consequence the complete record of the corrosion progress is not illustrated. In a general way the western exposure is an approximation of what existed on the eastern side of the stringers, but there were some glaring exceptions. Sometimes a better resistance to the corrosive environment was evident on one side than on the opposite side even though all other factors were nearly identical as possible to get under conditions of application. The extreme northern panel is not shown because sandblasting was already under way preparatory to repainting at the time these pictures were taken.

Discussion of Results:

Time has been considered an "equalizer" by corrosion and protective coatings experts when making comparative studies of paints. While this position might be subject to some modification in specific cases, the trends noted in this work would confirm its soundness. In such environment as the Leffingwell Bridge it seems safe to assume that all coatings tried would eventually have ended up in total failure. The test may be considered similar to a horse race in inverse order — the best coating finishes last.

It would be very difficult to make a definitive selection of any one coating as being consistently the best or worst of the series used in this experiment. Identical coatings in different locations showed up with vastly different performances. Note, for example, Panels 9H and 10H, Fig. 12, as compared with 9N and 10N, Fig. 7. Here is a spread of performance from one of the very poorest to one of the better. This example, perhaps one of the more extreme, is repeated, in part, in almost every case of duplicate panels. Another example which bears heavily on this characteristic may be seen in Panel 4N, Fig. 8 and 9. Note the sharp distinction between this panel and the adjacent Panel 5N, Fig. 8. Panel 4N is much superior to 5N near the boundary, but notice the heavy corrosion at the right of the brace. Could anyone make an accurate comparison of the two coatings from these two panels or, for that matter, of the Panel 4N alone? The effects of the braces are apparent in nearly every case as are those of the piers, but here again consistency is not a

feature of the effects. Panels 4H, Fig. 14 and 20H, Fig. 17, 18, are badly corroded on the left of the brace; Panel 4N, Fig. 8 and 9, corrosion is mostly on the right side of the brace, while that of Panel 20N, Fig. 2 and 3, is pretty evenly distributed on each side of the brace. These inconsistencies within the individual panels are not so readily discernible from the photographs as they were from direct inspection where angular viewing could be eliminated.

Passing now to the piers and their effect on the areas of corrosion, it is not so easy to find contrasts. There is no single panel that has been completely within the projected vertical boundaries of a pier. This being the case, there are no identical coatings on either side and adjacent to a pier. Nonetheless, one can deduce some effects. Without belaboring the point extensively, let us examine the Panels 8H, Fig. 12 and 7H, Fig. 13. There is a pier centered between the two. Of course, Panel 8H has a great disadvantage in being untreated and having only one aluminum coat. However, it is doubtful that the extreme difference in the performance of the two panels would obtain if the environments had been identical. The reader may discern other cases which appear incongruous.

He may notice, also, some features which are very revealing. Specifically, examine Panels 8H and 9H, Fig. 12 — the boundary between them. Note that an area six or eight inches in width extending across the entire span is relatively well protected. This must be due to overlapping of the two coatings. Individually,

both of these coatings have failed miserably, but where they have been piled up on each other extra coats and probably extra thickness have afforded protection. Other panels may show a similar effect.

It will be recalled from earlier reports that the southern section of this bridge had been shrouded in canvas and that the air thus entrapped was heated in an attempt to exclude possible salt spray from the steel and to facilitate drying when the paint was applied. The futility of this step is now apparent since the southern part of the bridge, except at the extreme end where air currents presumably are deflected somewhat, is far more corroded generally, than the northern section. The northwesterly winds, which are practically continuous, can be credited with this phenomenon since the currents are probably deflected a bit by the higher earth as shown in Fig. 1. It seems reasonable to assume that all the various anomalies that are so prevalent in the results of this work may stem from the wind currents and the deflecting influence of the members of the bridge as well as from the variable ground elevations. The stringers themselves apparently exert a considerable influence on the resistance offered by other stringers. Their influence must be due to the baffling of currents of salt and moisture carrying winds which deposit their loads on the upper reaches of the landward stringers. It is evident from the photographs also that the exterior seaward stringer generally shows less corrosion than the interior stringers in the same relative position though this is by no means consistently so. Probably the rains striking this stringer removed

the deposited salt during the winter season. The interior stringers are shielded by the bridge deck. The landward exterior stringer outside exposure did not exhibit this contrast as much as the seaward member did. Again the northwesterly winds would account for this perhaps, since the landward stringer would be shielded from wind driven rain to a great extent. But why isn't the appearance consistent? The most reasonable hypothesis would appear to be the baffling effect of the piers, braces and stringers to the extent of diverting the normal flow of winds into such patterns as to cause the salt to deposit irregularly. It is known that the salt deposit on the stringers is not at all uniform. And, of course, the winds themselves are irregular. One may assume that the fog and unsalted winds are likewise subject to irregular patterns of impact and deposit with the result that irregular concentrations of salt solutions and areas of non-uniform salt penetration of protective films by diffusion are successively created and destroyed. When one considers the sustained persistence of these cycles it becomes clear that the most effective protective coating in such areas is likely to be of the barrier type — that is, a coating that is capable of preventing the diffusion of water or water solutions through the film. Inhibitive pigments may be effective for awhile, but they are necessarily limited in time of effectiveness by the quantity of pigment available in a corrosive spot. If the electrolyte is excluded from the surface — permanently — corrosion cannot occur.

In the early stages of this test the observed beneficial effect of the pretreatment of the steel with phosphoric acid or vinyl wash primer was striking. At the latter end of the test the contrast between treated and untreated panels became less marked. This may be observed in the photographs in Panels 6H, Fig. 13, 14 and 7H, Fig. 13, as an example where adjoining panels were identical except for the pretreatment in Panel 7H. Panel 7H was showing the better performance but by a narrower margin at the end of the test. Nevertheless, in general, the pretreated sections have shown definitely superior performance compared to the untreated sections. This was particularly noticeable in the matter of undercutting the film where corrosion had started.

It is worth recording, perhaps, that the Bridge Department wished the experimental painting of the bridge to be characteristic of the type of job that was available in 1952 from good reliable contractors. No attempt was made to build up the flange or rivet head coating over that obtained elsewhere on the structure. It was strictly a "coat" job with no emphasis on film thickness beyond a "good" coverage by each coat. That was the prevalent procedure in our painting specifications. About that time, however, a thickness gauge was obtained by the Materials & Research Department. This gauge was placed in the hands of Paul Jurach, Inspector on the job, for the purpose of determining what film thicknesses were being obtained. Mr. Jurach took several thousand thickness readings and recorded area averages of the entire bridge.

A very detailed thickness profile or contour drawing compared with a similar corrosion contour might have brought out some interesting statistical correlations, but the detailed measurements were not made. In any case, we have sufficient data from subsequent tests to fully substantiate the virtue of thick films compared to thin films, especially when the film is applied in multiple coats.

Probably the greatest value obtained from taking the large number of thickness measurements lies in having emphasized the lack of uniformity of coatings applied under earlier specification codes. These measurements varied from 2 to 7 mils and the variation was general. The dry film magnetic thickness gauge (the Elcometer) now in use permits the enforcement of specifications stipulating thickness of film as well as number of coats. Such specifications have been adopted by the Bridge Department. Obviously, this change in approach to specification requirements was not entirely due to the work on Leffingwell. Subsequent tests and published results from other sources were considered of course.

If one were forced to make a selection of the more proficient coatings on the basis of the data available from this test alone, he would probably have to choose the Vinyl Epoxy Red Lead, the Vinyl Red Lead compositions (in spite of the inconsistencies) or our present Quick Dry Red Lead, State Specification 53-G-53. In view of the very good results apparent in Panels 17N, 18N, 19N, all in Fig. 4, and in Panels 17H, 18H, 19H of Fig. 16, one may wonder why the VERL - Vinyl Epoxy Red Lead - has not been exploited.

The same position might be taken with regard to the vinyl coatings with perhaps less apparent reason. The vinyl epoxy composition was made and used without any previous data other than from laboratory investigation — more or less a shot in the dark. Commercial production of this article proved to be very difficult and almost impossible to duplicate continuously. Incompatibilities developed in storage. They are difficult to adjust for application. Some vendors have confirmed this from their experience. It has been dropped by experimenters in most of the larger paint firms.

The vinyl used here has been modified extensively for large scale production and as such has been used for large scale trials. It is the observation and considered opinion of this writer that the use of red lead or other inhibitive pigment is not justified in such vehicles as the vinyl chlorides. Some technologists do not agree with that opinion, but no proof to the contrary has been brought out. Vinyl paints were used exclusively on two large bridges in 1954 as an experiment. No inhibitive pigments were used at all. The performance is really better than that which we observed on Leffingwell after four years exposure.

The Semi-Quick Dry Red Lead has been used more than any other specification since dropping the old Red Lead No. 3. When applied according to specifications mentioned earlier it has performed well.

The Red Lead Phenolic - RLPh - as it appeared in this work, was somewhat disappointing. Because of its fine performance in the

penstock of Shasta Dam it had been included in the list of paints to try at Leffingwell. While its performance, all factors considered, was not hopeless, it was not what had been expected. This at least shows the vast difference between the corrosive effect of constant exposure to fresh water and a marine atmosphere.

The Red Lead Phenolic used on Panel 21N, Stringers 1,2,3, Fig. 2, and on Panel 22H, Stringers 1,2,3, Fig. 19, should have been labeled RLPh - X6. This formulation is a variation of the coating frequently used by the San Francisco-Oakland Bay Bridge and consists of Red Lead in linseed oil reinforced with the State Specification Aluminum Varnish. The vehicle is not greatly different from that used in the other RLPh series but the performance — so far as we can judge from its limited trial — seems to be better. Of course, the location in each instance cited is recognized as more favorable generally than most of the RLPh series of panels.

Conclusions:

This work has established the fact that many uncontrolled variables are operative on this steel structure.

Pretreating steel with phosphoric acid or vinyl wash primer increases the efficiency and "longevity" of the protective coatings.

Painting under "coat" type specifications gives rise to great irregularities in film thickness of coatings and performance of the same.

Some superiority of certain types of paints may be deduced from the test.

APPENDIX

A. SEMI-QUICK DRYING RED LEAD PAINT

Batch N-221

97% Sublimed Red Lead	131	pounds
Talc	23	"
Aluminum Stearate	0.25	"
Raw Linseed Oil	20	"
TT-R-266, Type III at 60% Non-volatile	31	"
Mineral Spirits	10	"
24% Lead Naphthenate	1	"
6% Cobalt Naphthenate	0.2	"

Weight per gallon	20.43	pounds
Viscosity	98	KU

B. 80% ZINC CHROMATE

Batch N-218

Zinc Chromate	41	pounds
Zinc Oxide	6	"
Yellow Oxide	1.5	"
Talc	6	"
Aluminum Stearate	13	ounces
Alkyd Resin as per specification 60% Non-volatile	40	pounds
Dipentene	2	"
Socal #2	17	"
6% Manganese Naphthenate	2	ounces
6% Cobalt Naphthenate	2	"
24% Lead Naphthenate	1	pound

Weight per gallon	11.5	pounds
Viscosity	75	KU

C. RED LEAD AND OIL (#3 PRIMER)

Batch J-649

97% Sublimed Red Lead	398	pounds
Metal Lead Powder	52	"
Raw Linseed Oil	87	"
Mineral Spirits	6	"
6% Cobalt Naphthenate	0.25	"
6% Manganese Naphthenate	0.25	"
24% Lead Naphthenate	1	"

D. RED LEAD PHENOLIC (M & R FORMULATION)

Batch M-675

97% Sublimed Red Lead	63	pounds
Zinc Chromate	10	"
Zinc Oxide	5	"
Mica	11	"
Talc	15.5	"
Aluminum Stearate	0.5	"
Bakelite Varnish	7	gallons
Mineral Spirits	2.375	"
Dipentene	1	"
Anti-Skin	0.375	"
6% Cobalt Naphthenate	50	gms

Weight per gallon	14.78	pounds
Viscosity	83	KU

E. RED LEAD PHENOLIC (SFOBB FORMULATION X-6)

Red Lead	93 pounds	=	1.265 gallons
Linseed Oil	7 "	=	0.9 "
Aluminum Vehicle	38 "	=	5.0 "
	138 pounds		7.165 gallons

138/7.165 = 19.26 pounds per gallon, Type X3

	138.000 pounds	7.165 gallons
Mineral Spirits	0.875	.125
	138.875	7.290

138.875/7.29 = 19.05 pounds per gallon, Type X6

F. VINYL RED LEAD (FORMULATION #1)

Batch N-219

97% Sublimed Red Lead	85	pounds
Tribase	1	"
Vinyl VAGH	12	"
G 60	8	"
MiBK	43	"
Toluol	17	"

Weight per gallon	14.9	pounds
Viscosity	81	KU

G. VINYL RED LEAD (FORMULATION #2)

97 % Sublimed Red Lead	85	pounds
Tribase	1	"
Vinyl VAGH	12	"
G 60	8	"
MiBK	20	"
Toluol	20	"
Butanol	3.5	"
Cellosolve Acetate	8.5	"
Xylol	8	"

H. VINYL-EPON RED LEAD (FORMULATION #1)

Batch N-217

97% Sublimed Red	50	pounds
Tribase	0.5	"
Epitex 120	10	"
Vinyl VAGH	6	"
G 60	2	"
MiBK	25	"
Toluol	5	"

Weight per gallon	14.8	pounds
Viscosity	83	KU

I. VINYL-EPON RED LEAD (FORMULATION #2)

97% Sublimed Red Lead	50	pounds
Tribase	0.5	"
Epitex 120	10	"
Vinyl VAGH	6	"
G 60	2	"
MiBK	10	"
Toluol	10	"
Butanol	2	"
Cellosolve Acetate	4	"
Xylol	4	"

J. #5 ALUMINUM FINISH COAT

Aluminum Paste	2.25	pounds
Vehicle	1	gallon

This vehicle shall be an oil varnish, the resinous portion of which shall be 100% phenol-formaldehyde type. The resin shall be BR 254 or BR 9432 or equal corresponding to Federal Specifications MIL-R-15184 or MIL-R-15189.

The varnish shall be 33 gallons in oil length, 30 gallons of which shall be tung oil TT-O-395, and 3 of which shall be alkali refined linseed oil, MIL-O-15180.

The volatile portion of this varnish, which shall not exceed 50% of the total weight of the varnish, shall consist of 90% mineral spirits and 10% turpentine or xylol. The drier content shall consist of the naphthenates of lead, cobalt and manganese in such proportion as required, provided however, that, based on oil content, the total amount of lead shall not exceed .3%, the cobalt shall not exceed .03% and the manganese shall not exceed .015%.

K. VINYL ALUMINUM (FORMULATION #1)

Batch N-243

Vinyl Vy HH	14	pounds
Standard Lining Aluminum Powder	8	"
G 60	1.5	"
MiBK	40	"
Toluol	40	"

Weight per gallon	7.8	pounds
Viscosity	63	KU

L. VINYL ALUMINUM (FORMULATION #2)

Vinyl Vy HH	14	pounds
Standard Lining Aluminum Powder	8	"
G 60	1.5	"
MiBK	27	"
Toluol	27	"
Butanol	4	"
Cellosolve Acetate	11	"
Xylol	11	"

VINYL THINNER

Batch N-220

MiBK	6	gallons
Toluol	4	"

PHOSPHORIC ACID WASH

Batch N-223

Isopropyl Alcohol	36	gallons
85% Phosphoric Acid	6	"
Water	8	"
Tergitol	50	gms

VINYL WASH

Base

Polyvinyl - Butyral resin	56	pounds
Zinc Chromate "insoluble type"	54	"
Magnesium silicate	8.0	"
Lampblack	0.6	"
Butyl alcohol, normal	125	"
Alcohol, ethyl	380	"

Diluent

Phosphoric Acid Wash (formulation given above)

Mix 1 volume of base to 4 volumes of diluent just prior to use.

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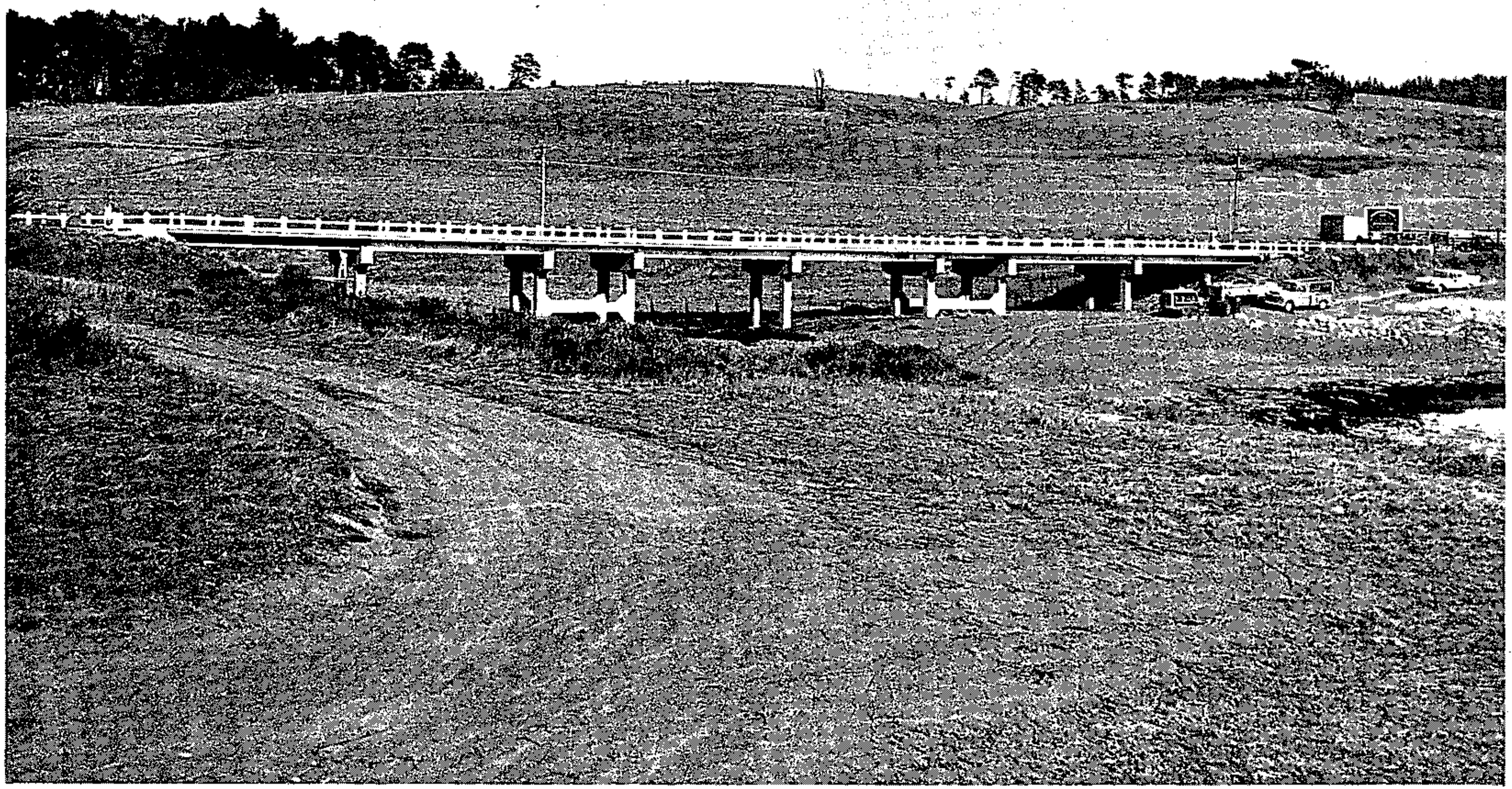


Fig. 1. Leffingwell Creek Bridge as viewed from near the Pacific Ocean surf line. This picture was taken in October 1958, just at the beginning of sandblasting operations for repainting.

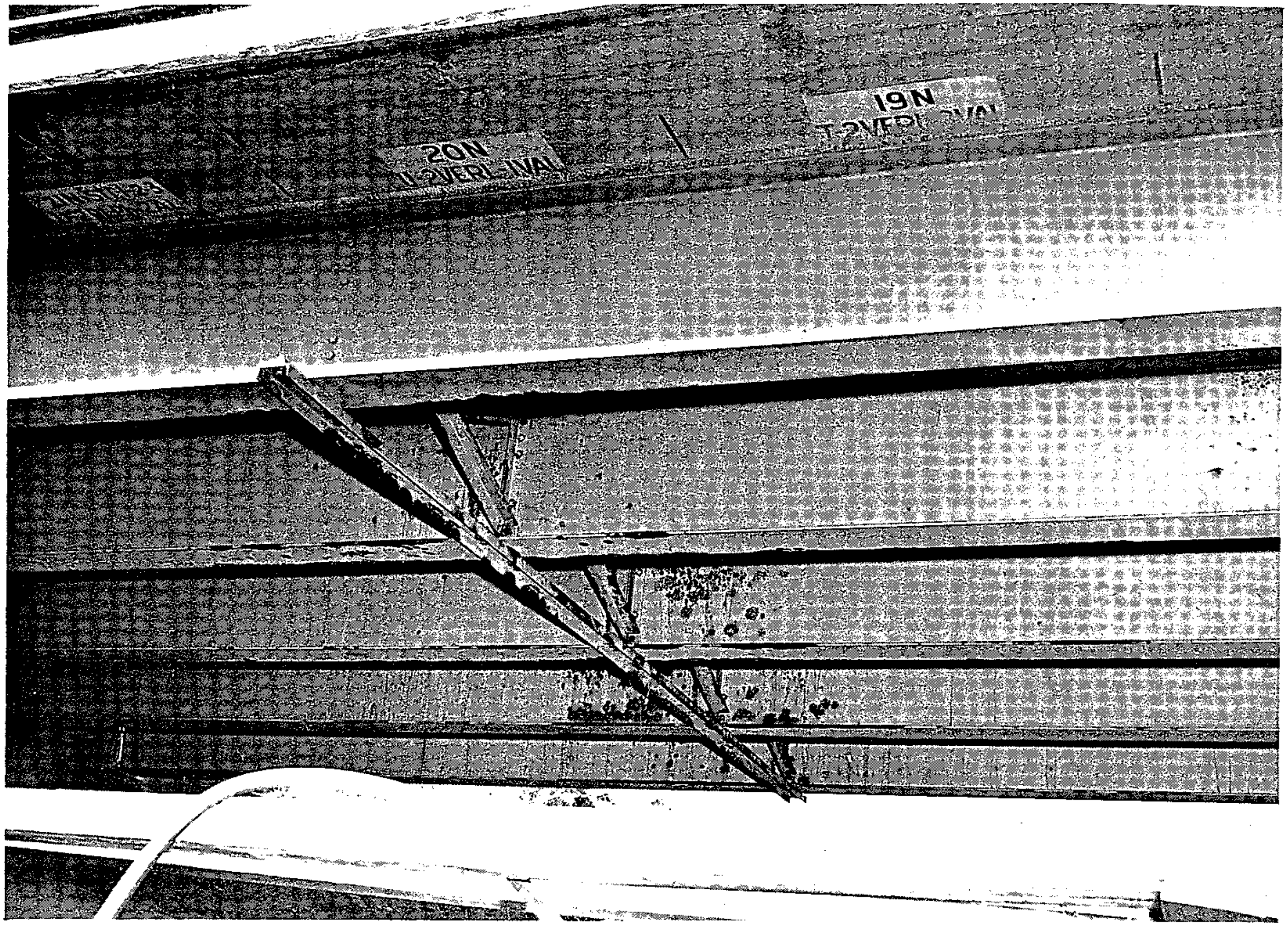


Fig. 2. The legend shown on the underside of the bridge deck describes the coating and whether steel was treated or not, e.g., Panel 20N indicates bare sandblasted steel was painted with two coats of Vinyl Epoxy Red Lead and one coat Vinyl Aluminum. Panel 19N steel treated with phosphoric acid, two coats of Vinyl Epoxy Red Lead - two coats Vinyl Aluminum.

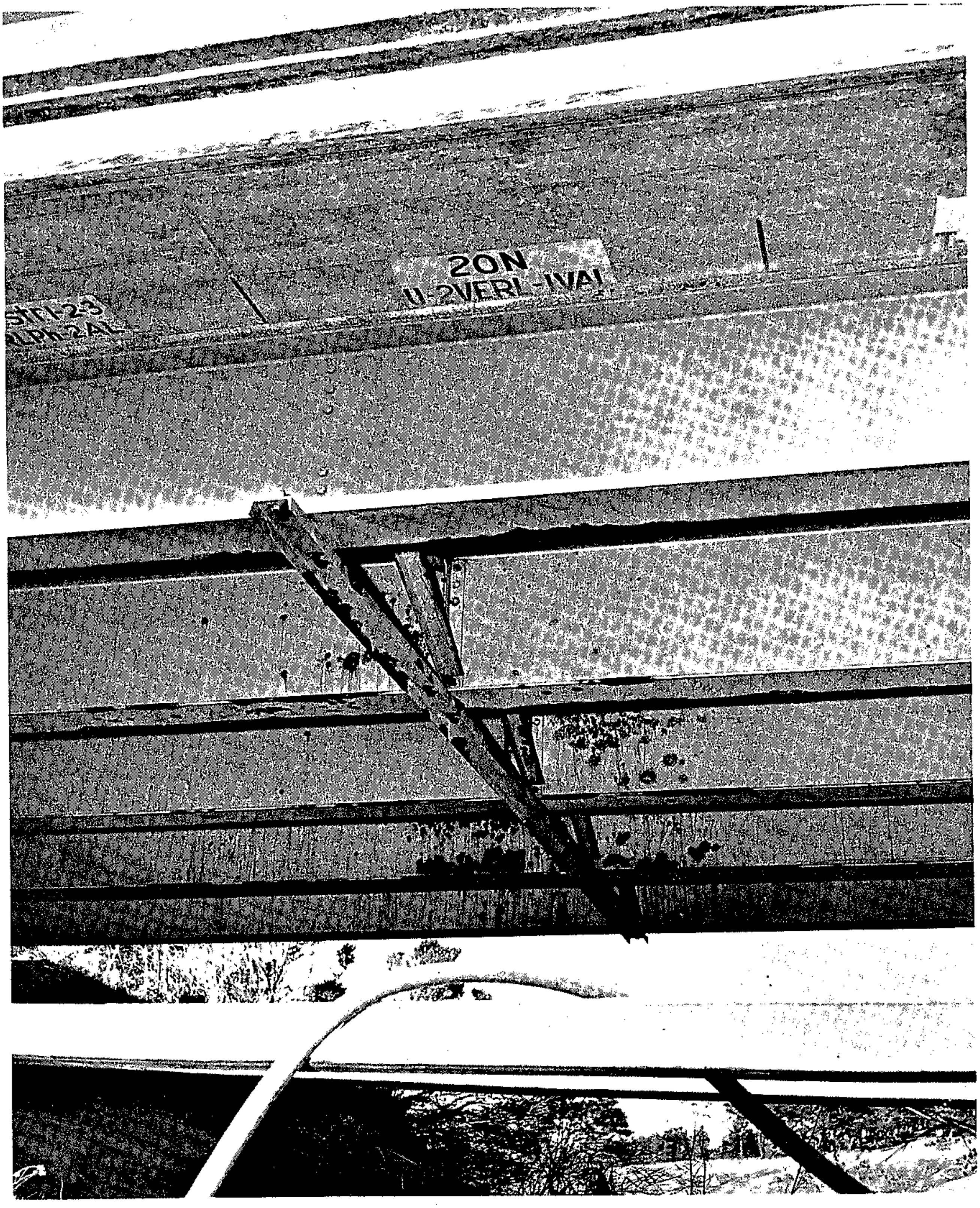


Fig. 3. A somewhat enlarged view of Panel 20N. Notice the apparent effect of the brace on the corrosion.

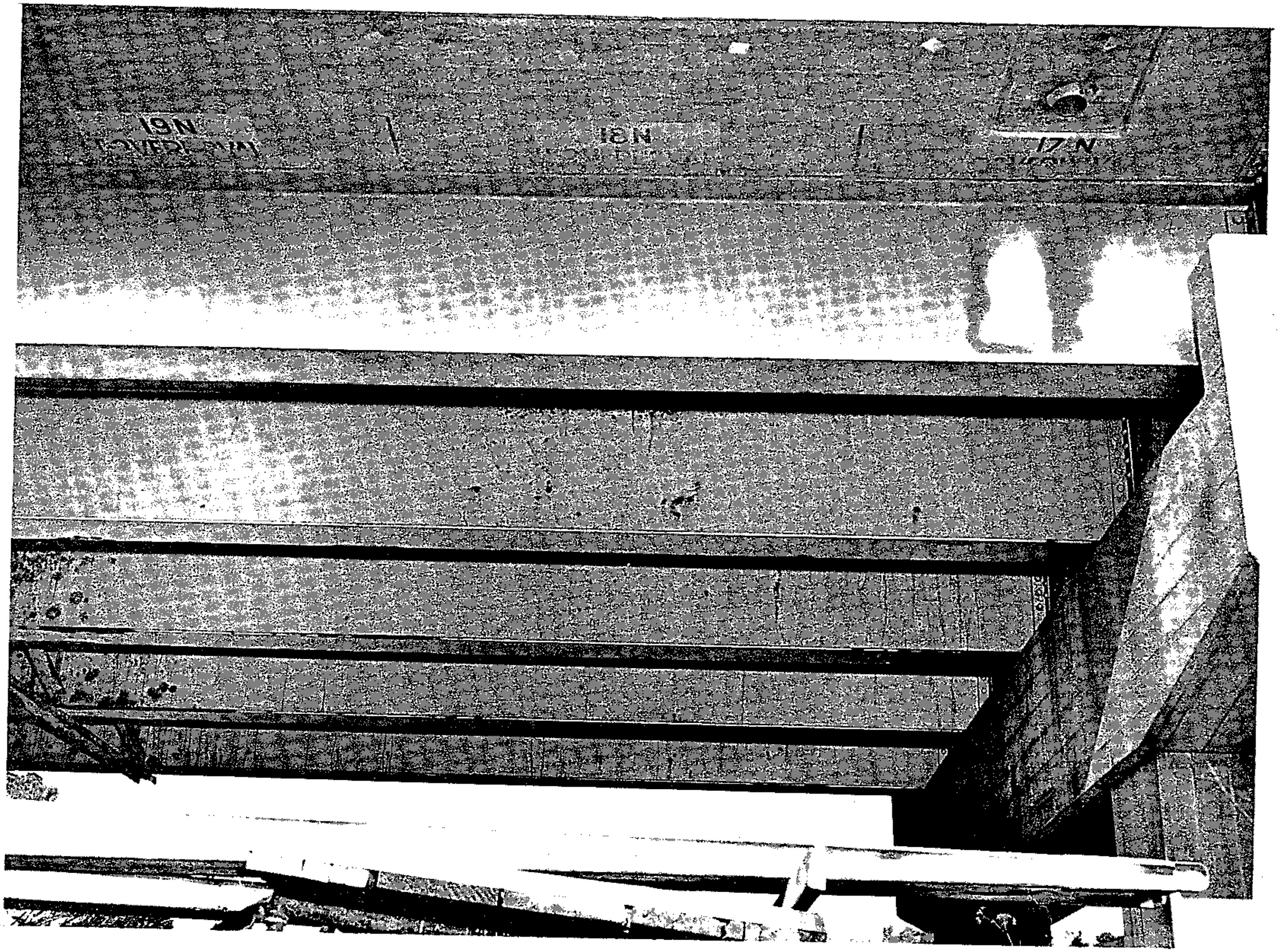


Fig. 4. Panels 19N and 18N were presumably given identical coatings except that 19N had the acid treatment, 18N none. Note the general better appearance of 19N.

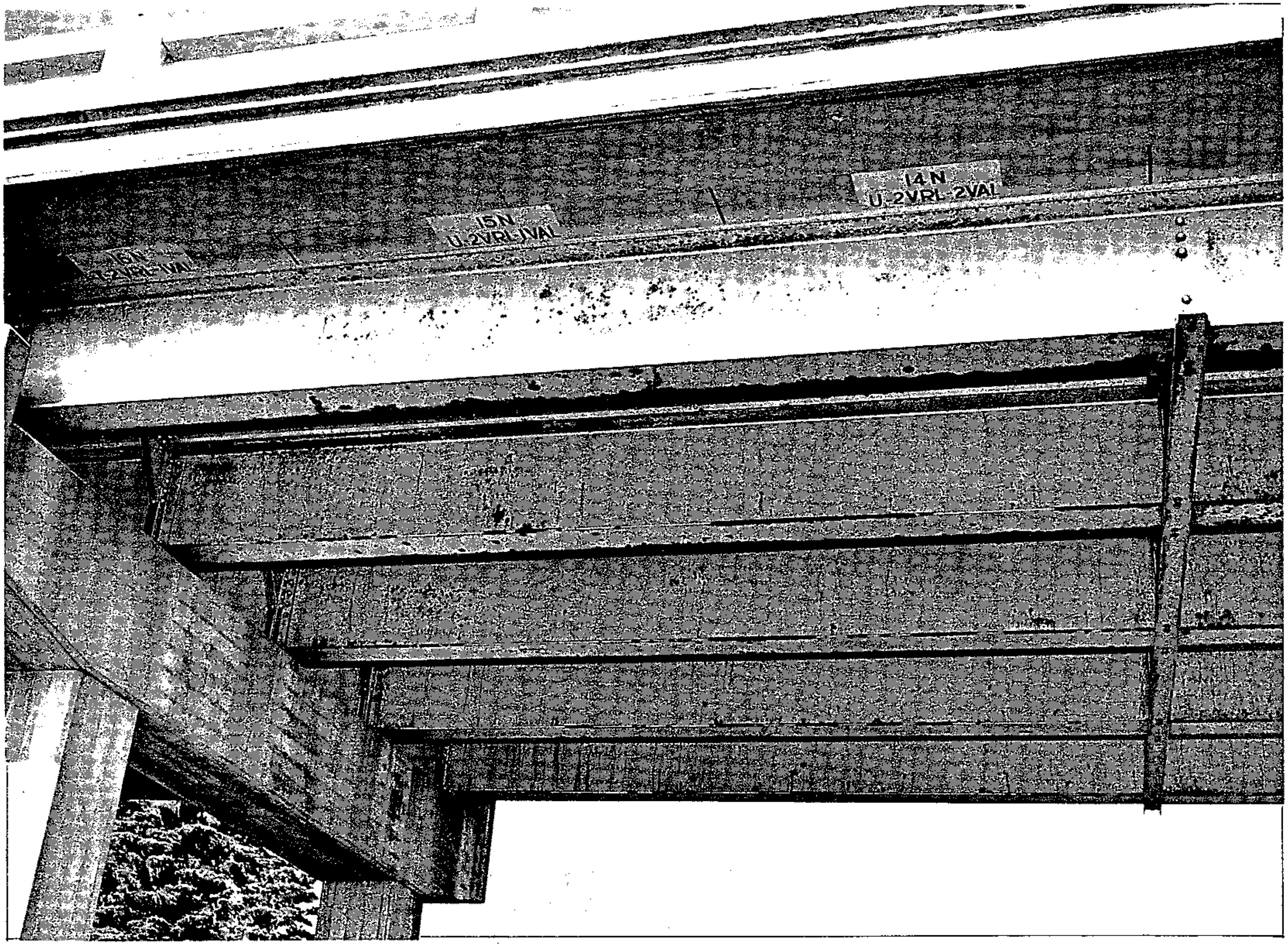
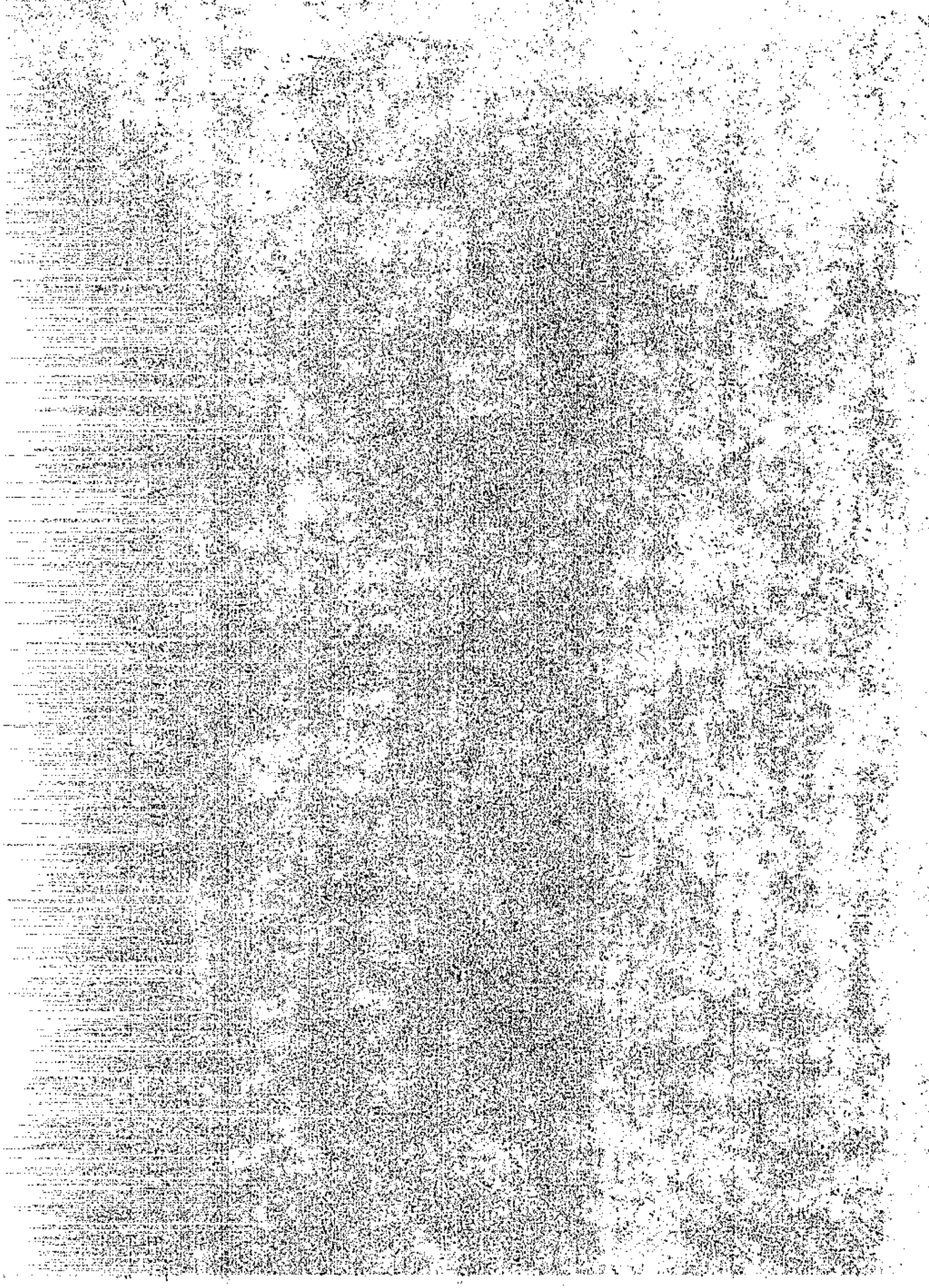


Fig. 5. The effect of the pier and brace in this section has probably been predominate.

Fig. 6. The effect of acid treatment of the steel seems to be very evident here in Panel 11N compared to untreated 12N, even with an extra coat of Aluminum.



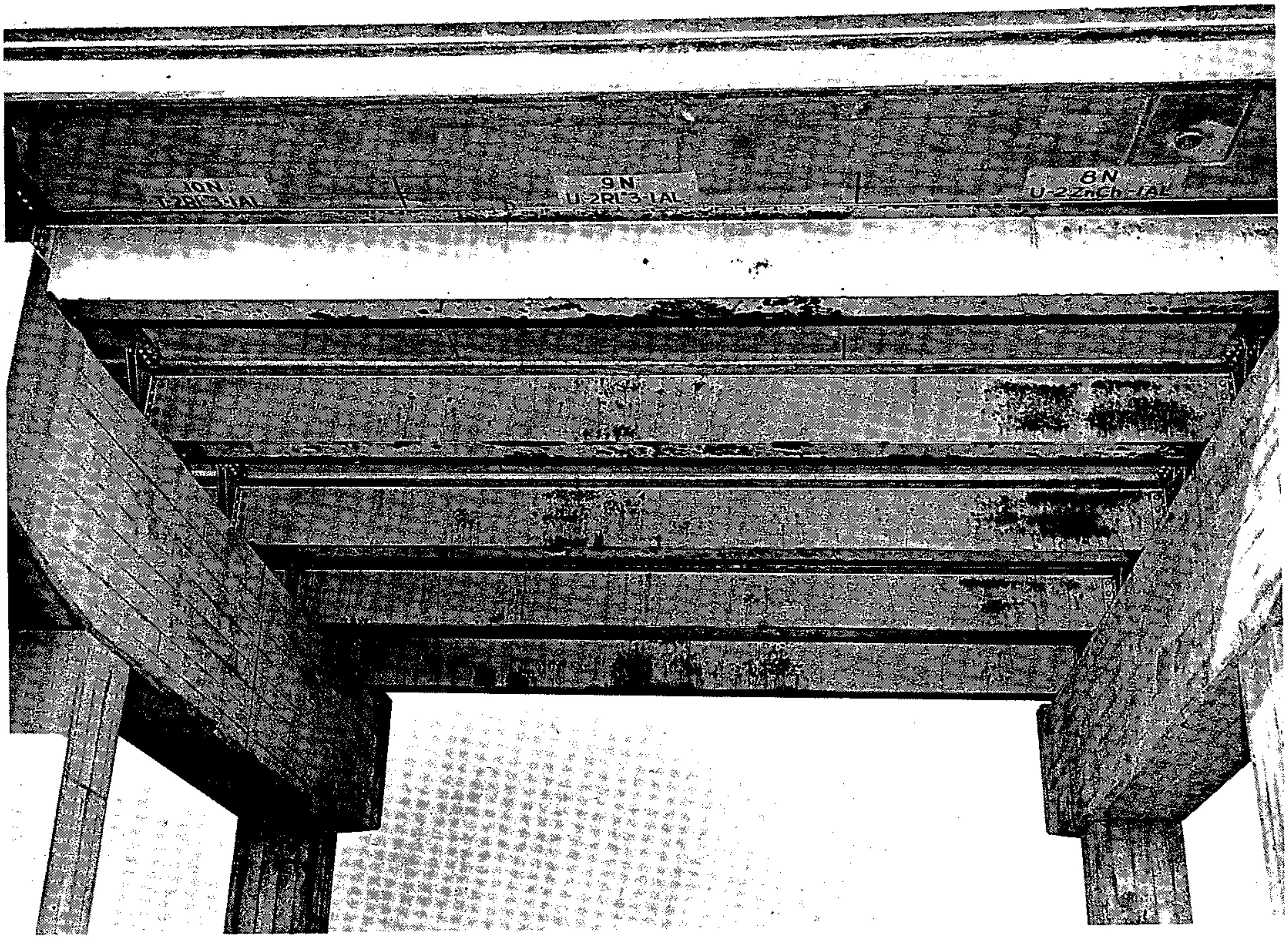


Fig. 7. Panels 10N and 9N seem to show the benefit of treatment in Panel 10N, although the effect of the pier alongside this panel is unknown.

Fig. 8. Here is a reversal from result noted in Fig. 7. Treated Panel 7N is in poor shape compared to untreated 6N, probably due to pier effect on wind currents.

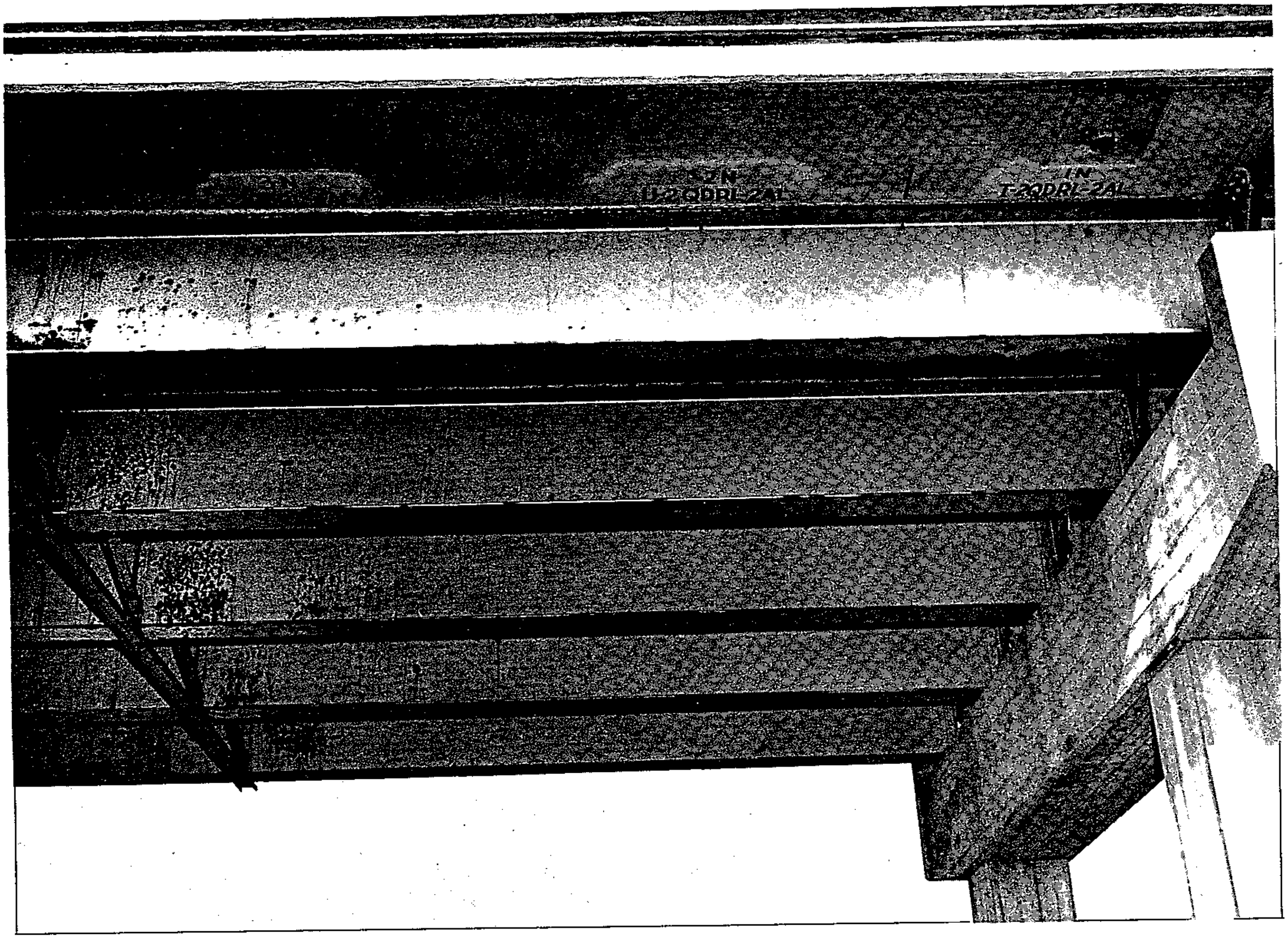


Fig. 9. Flanges in Panels 2N and 1N are badly corroded but there is little evidence of difference between the treated and untreated sections.

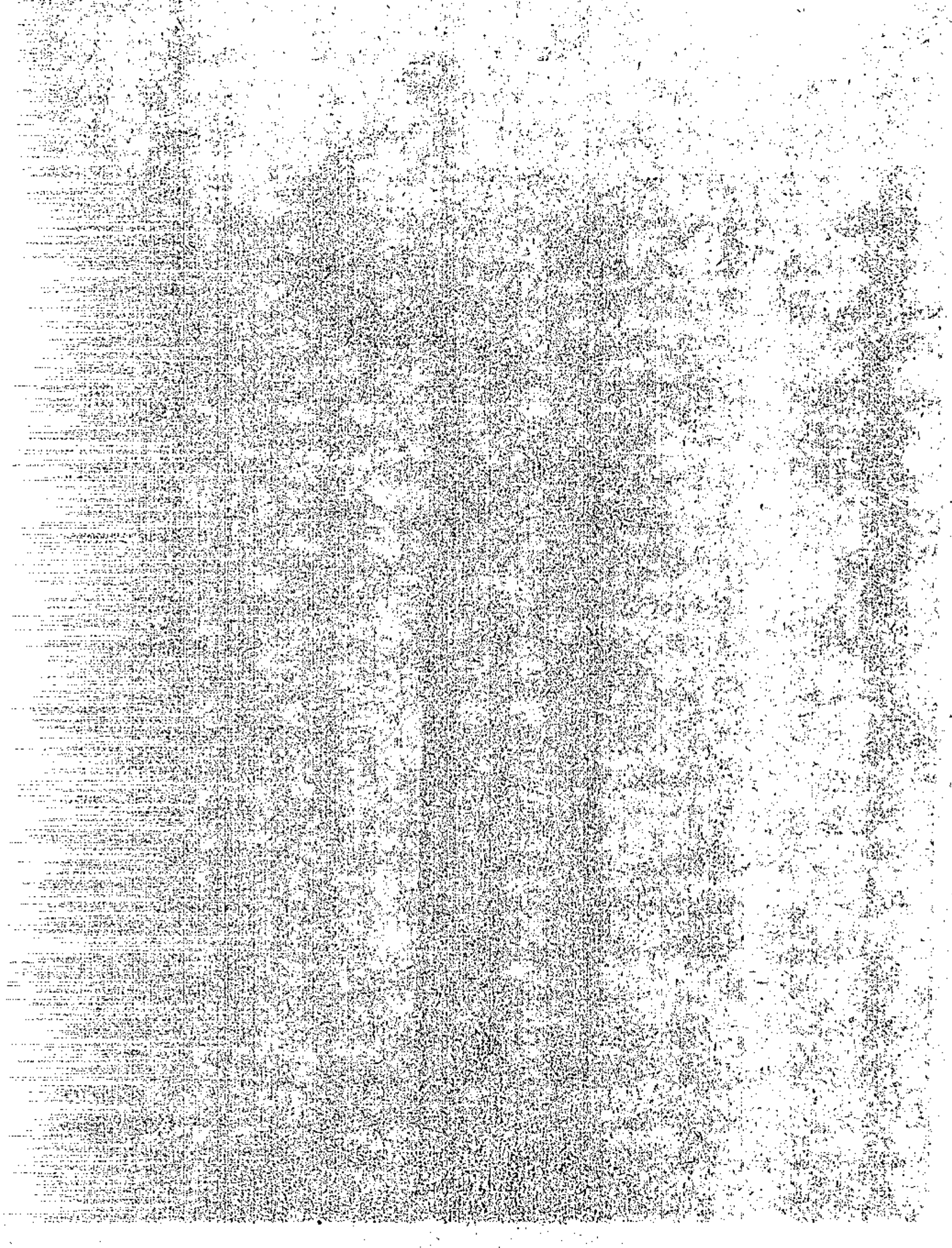


Fig. 11. Treated Panel 13H is in poor condition compared to Panel 14H, untreated. The virtue of the wash primer MIL-P-15328 has been well established but does not overcome the apparent adverse effect of the brace.

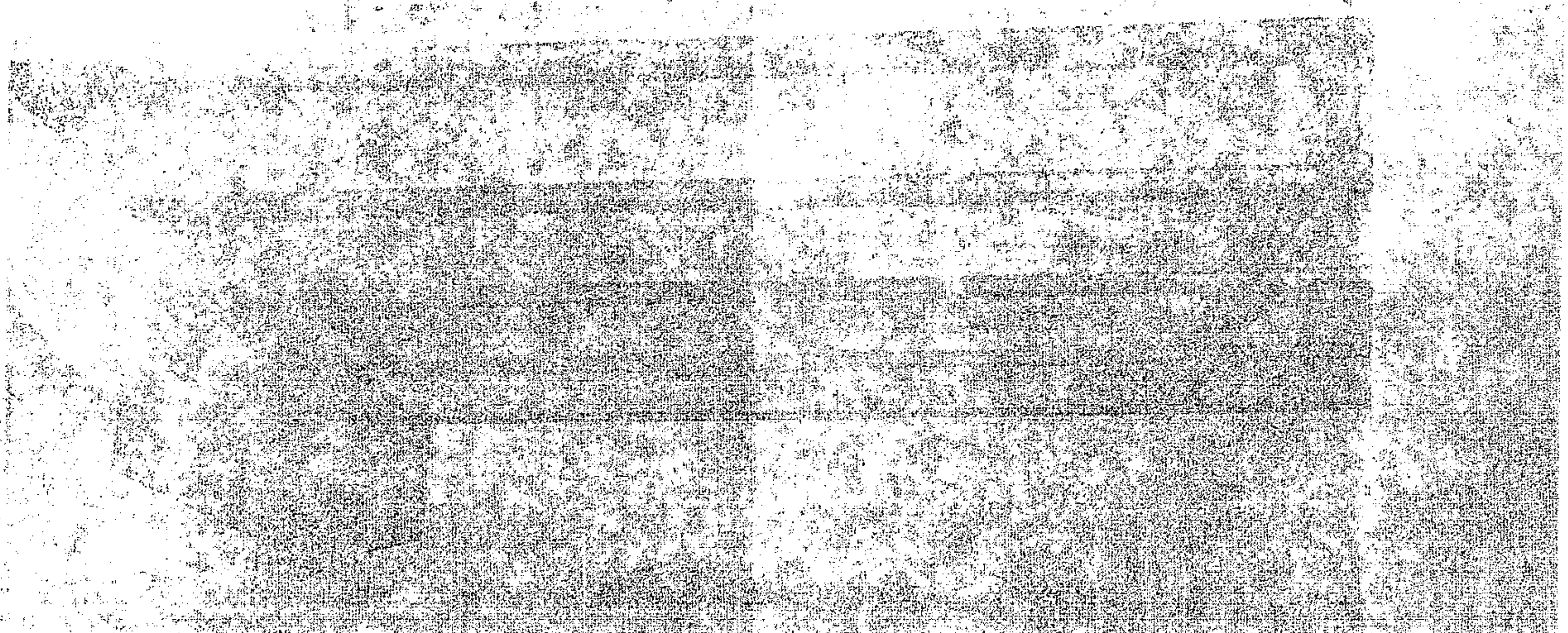


Fig. 11. [illegible] treated [illegible] 3) is in poor condition compared to plant [illegible] untreated. The [illegible] 1328 has been well established [illegible] does not overcome the [illegible] trees.

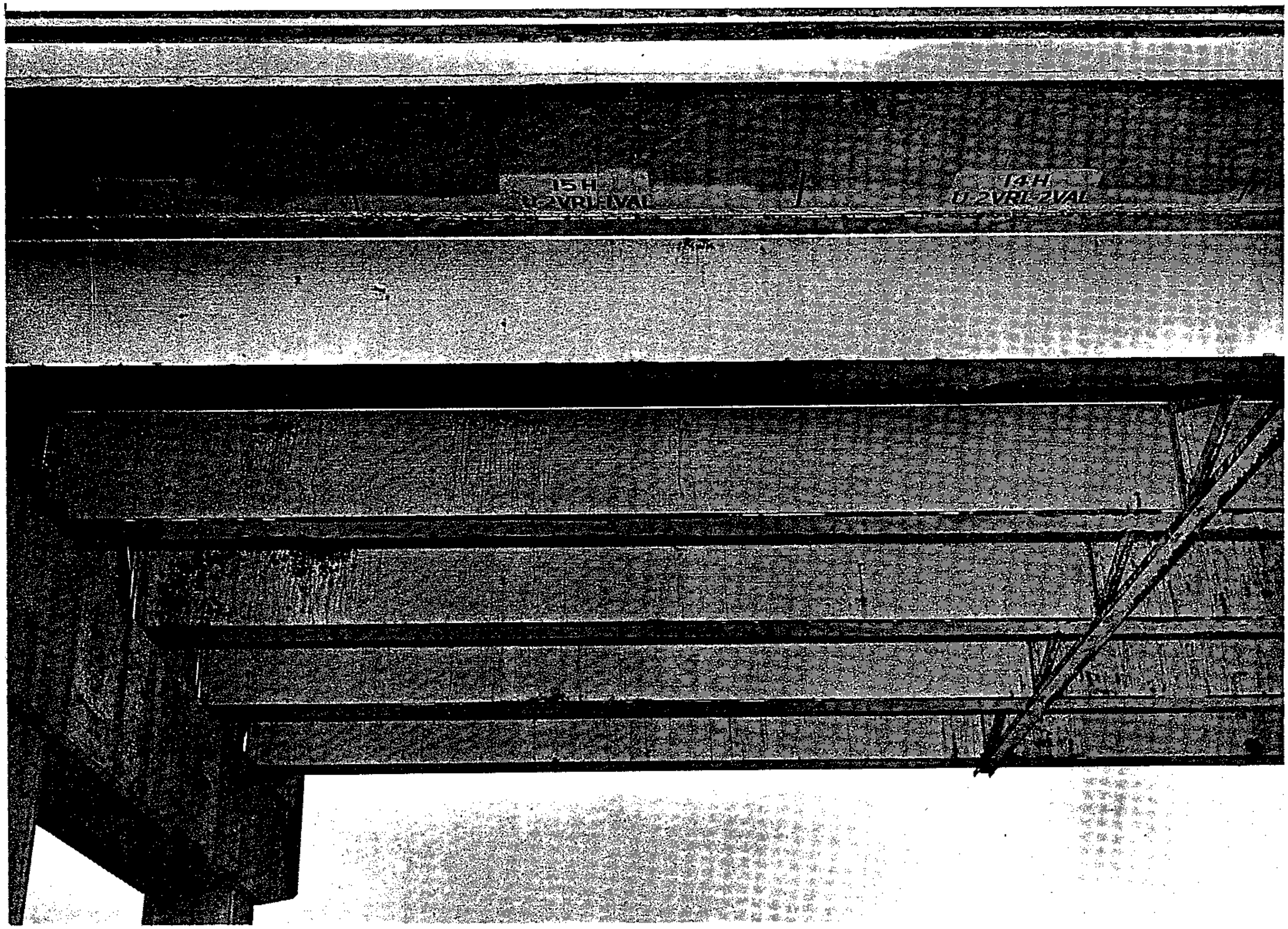


Fig. 10. The pretreatment of Panel 16H does not show to advantage here. The advantage appears to lie in the extra coat of Aluminum Finish in Panel 14H. Pier and brace probably alter the course of corrosion.

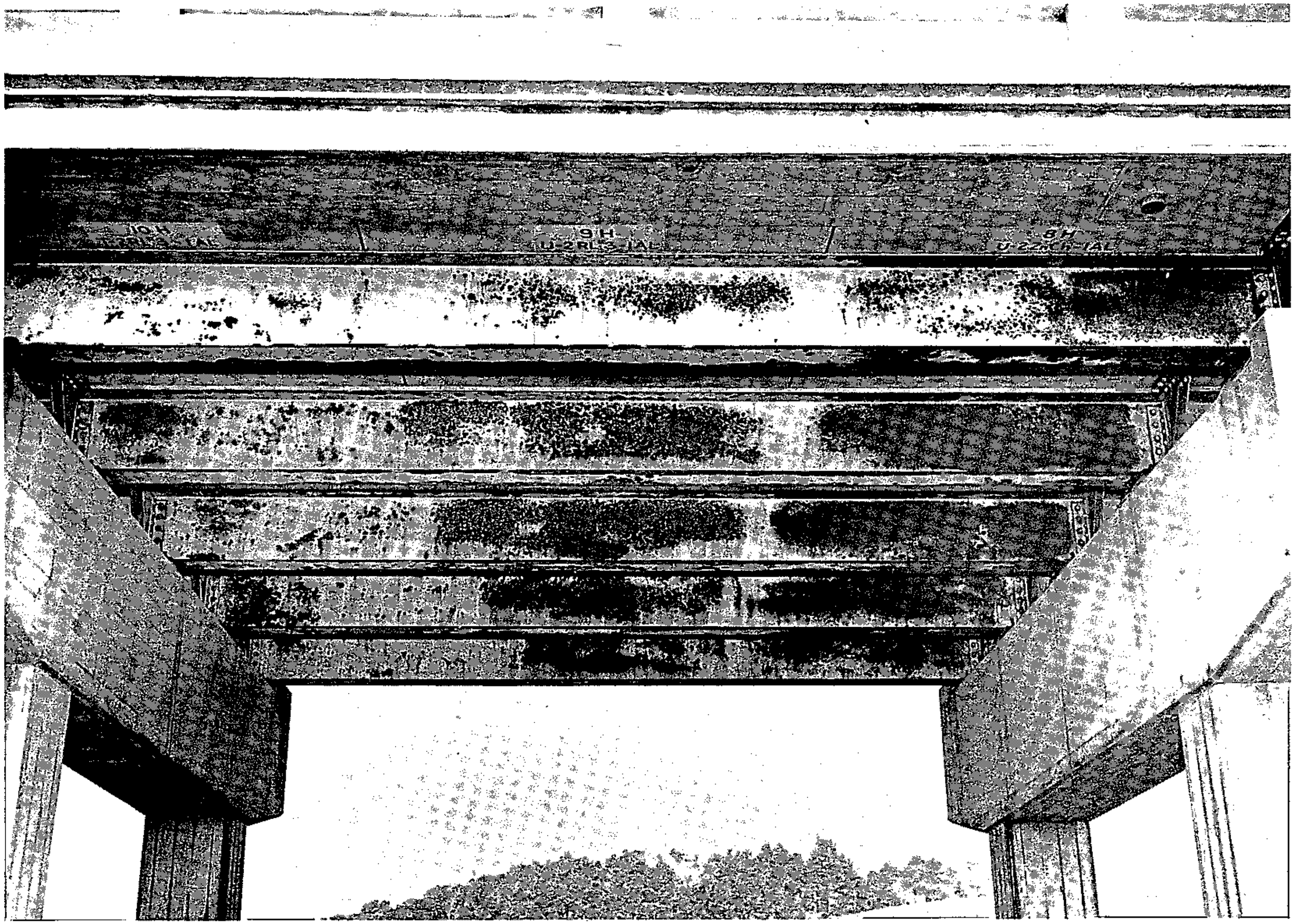


Fig. 12. Eliminating the first stringer which is subject to fresh rain and little of pier's wind diversion, note the regressing width of heavy corrosion on successive stringers. Probably due to sustained diversion by pier of salt carrying winds.

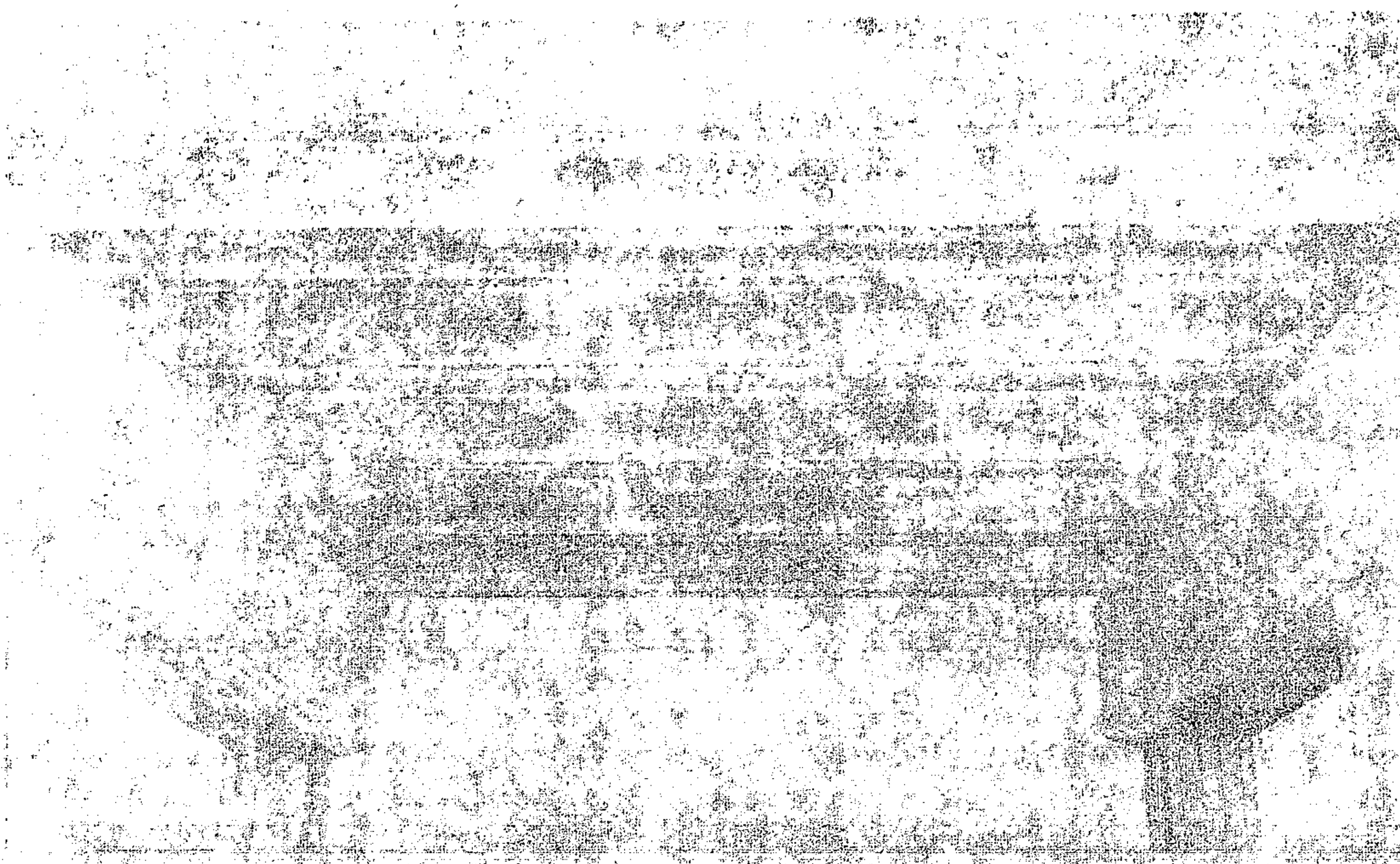


Fig. 12. Simulating the [illegible] which is subject to frequent and little of [illegible] correction or successive [illegible]
[illegible]

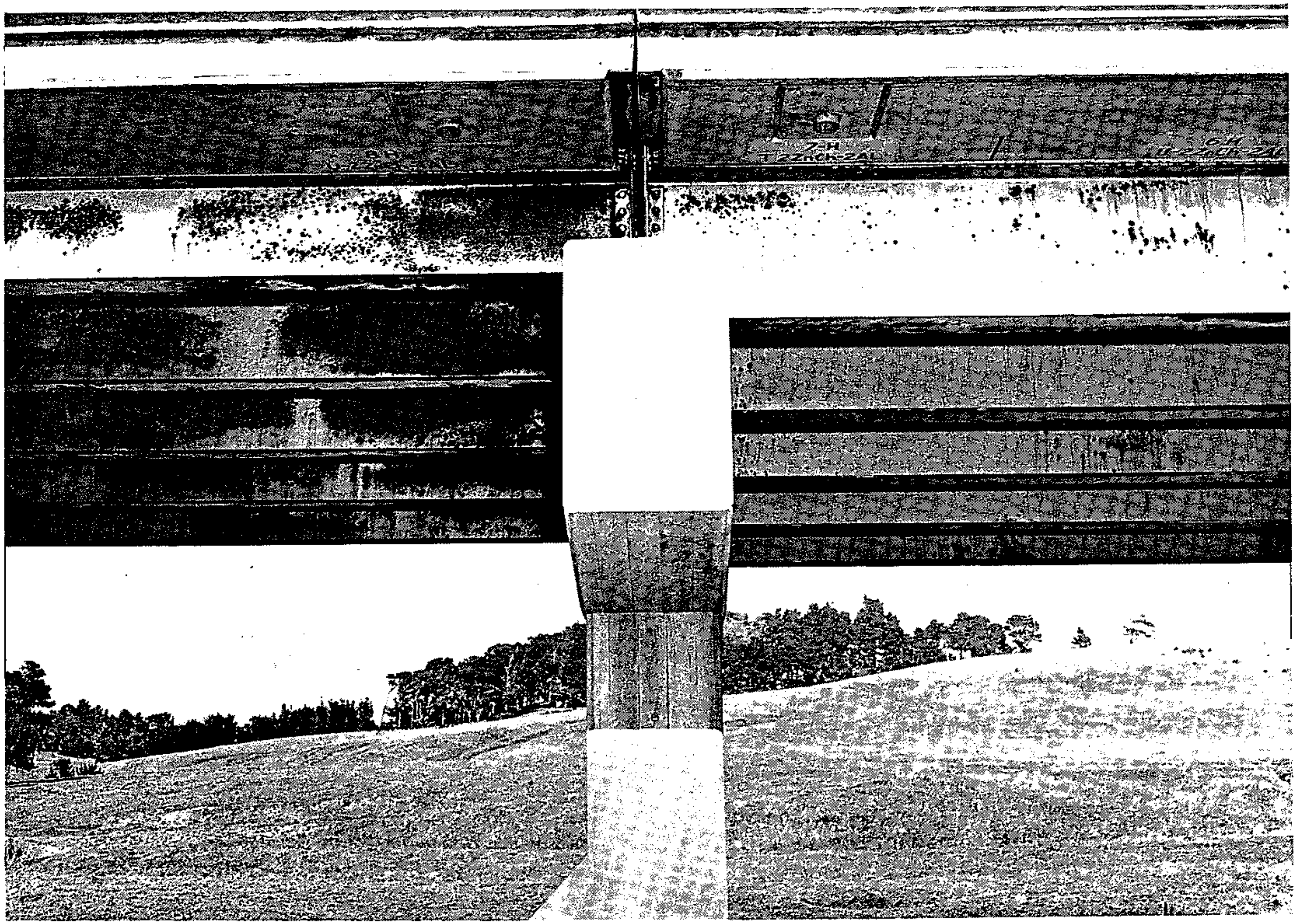


Fig. 13. Panels 8H, 7H and 6H, all given two coats of Zinc Chromate have performed here in accordance with what would be predicted, qualitatively.

Fig. 13. Results 58, 78 and 69, all seven locations of [illegible] performed here
[illegible] would be predicted [illegible] levels

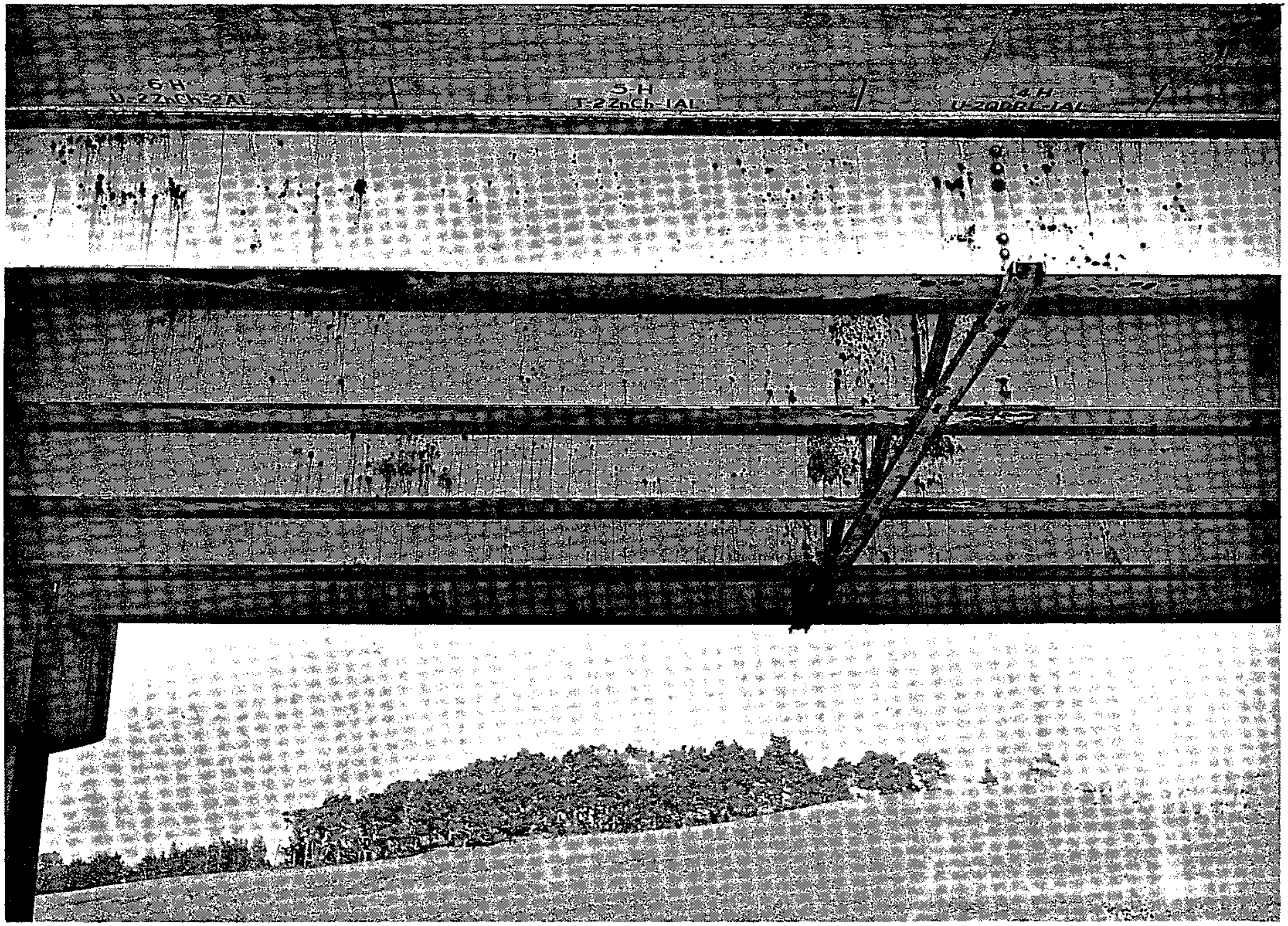


Fig. 14. Normal expectancy continues into Panel 5H. This treated panel with one coat of Aluminum Finish is about a stand-off with Panel 6H, untreated but with two coats of Aluminum Finish.

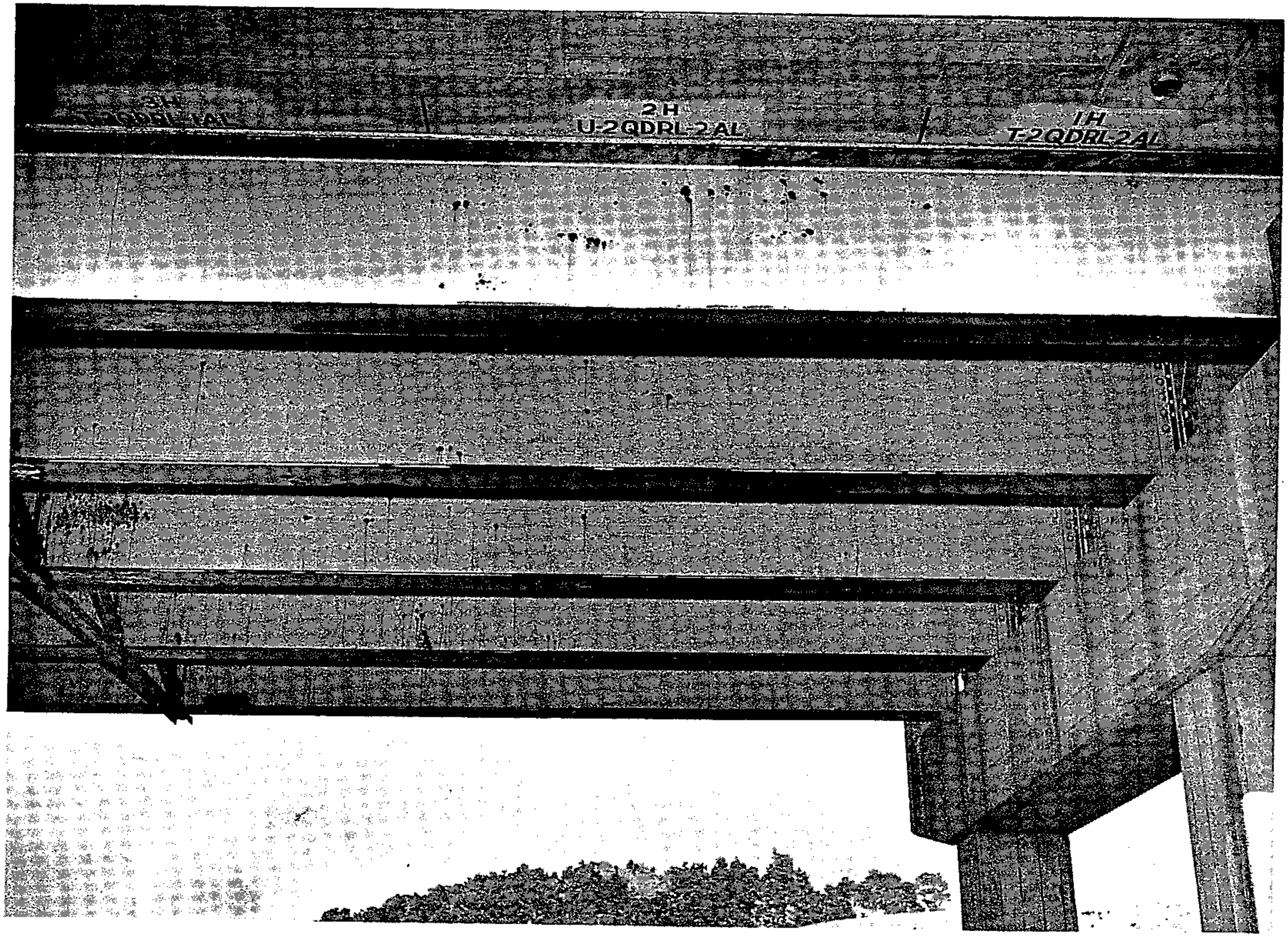
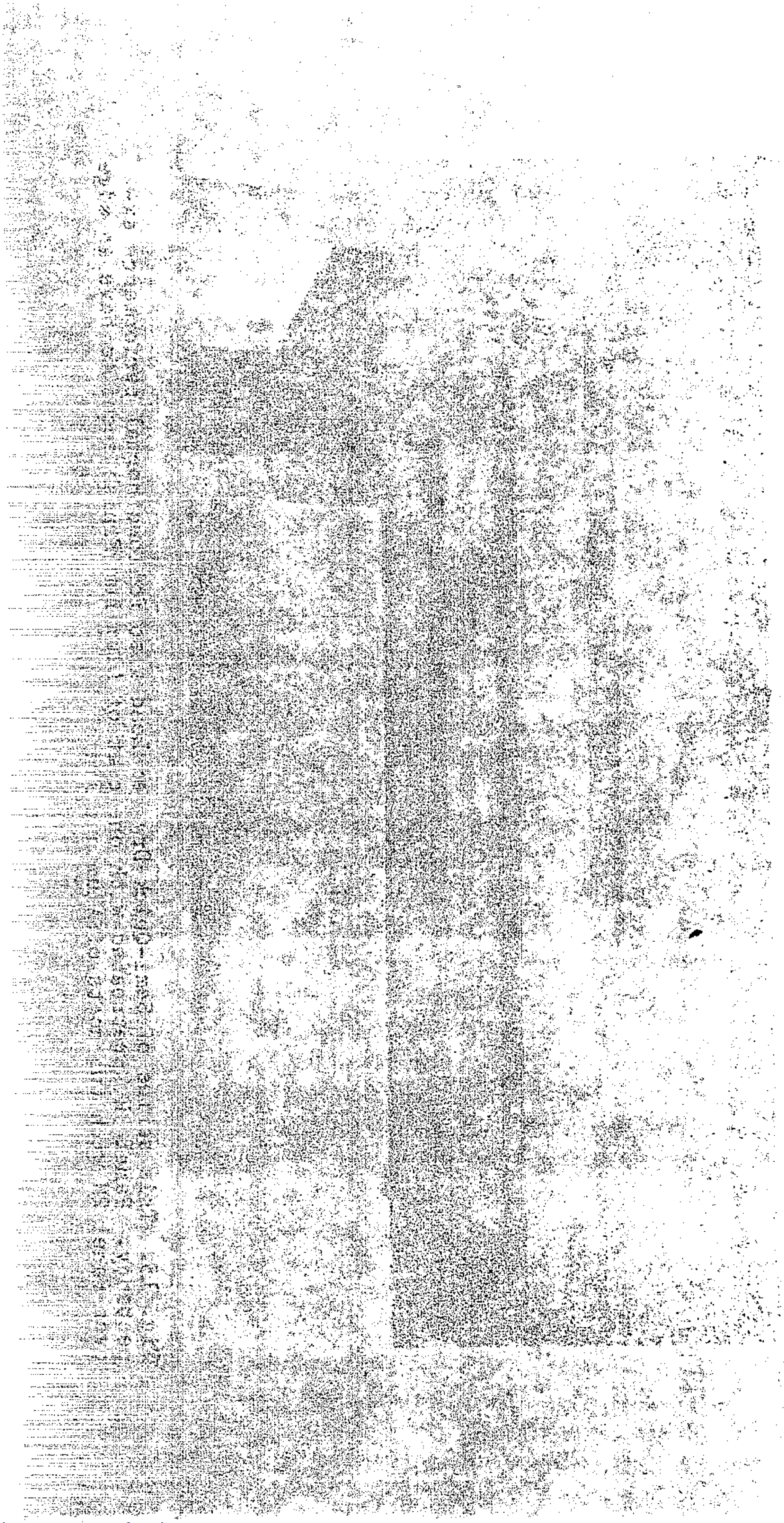


Fig. 15. This series of Semi-Quick Dry Red Lead also follows normal performance expectancy. Panel 3H, pretreated with one coat of Aluminum Finish seems to have an edge over Panel 2H with two coats of Aluminum Finish.



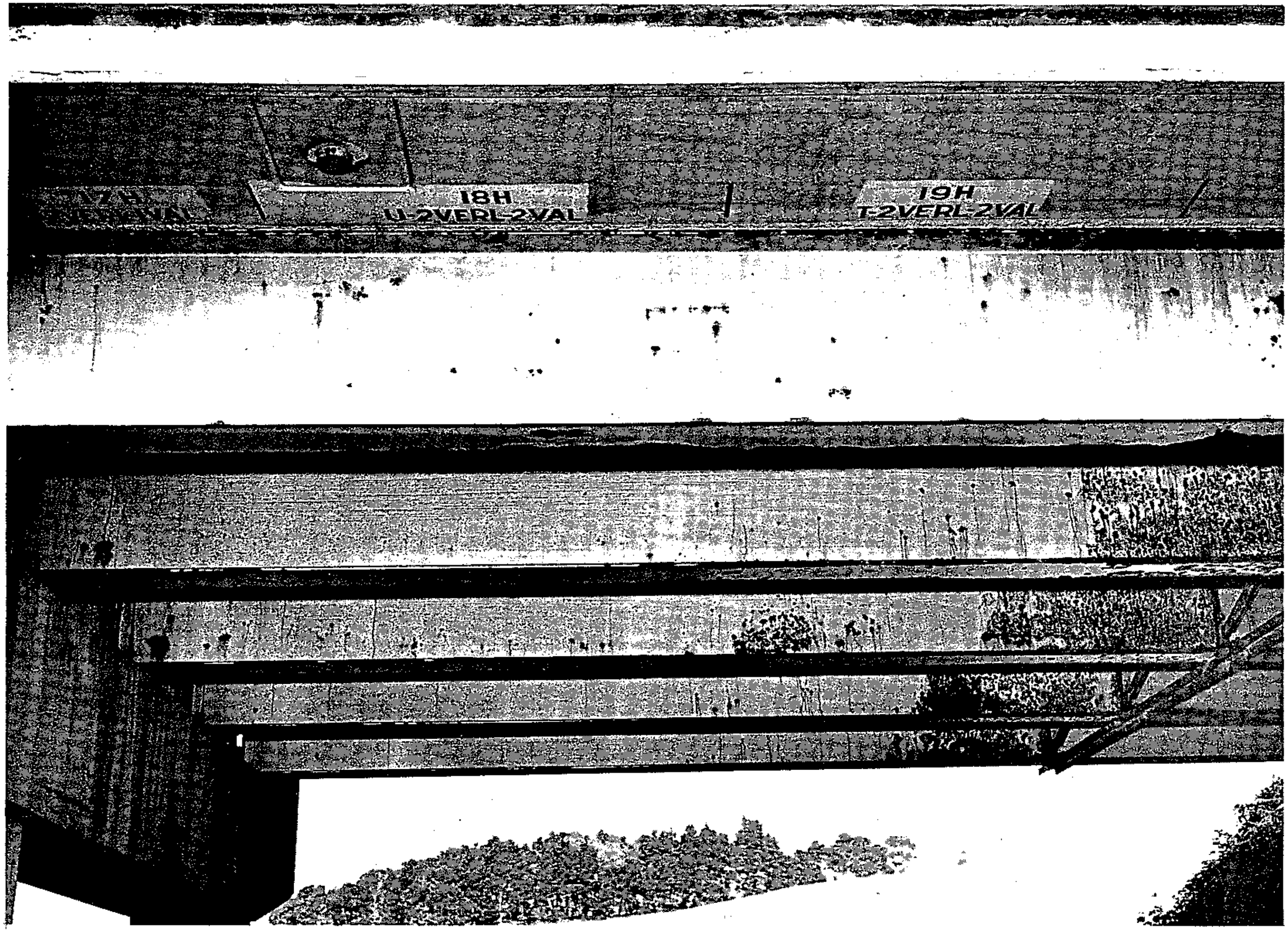


Fig. 16. This series of Vinyl Epoxy Red Lead coatings does not entirely conform to expected results. However, note the vast superiority of Panel 19H over 20H as indicated by the sharp dividing line between the two.

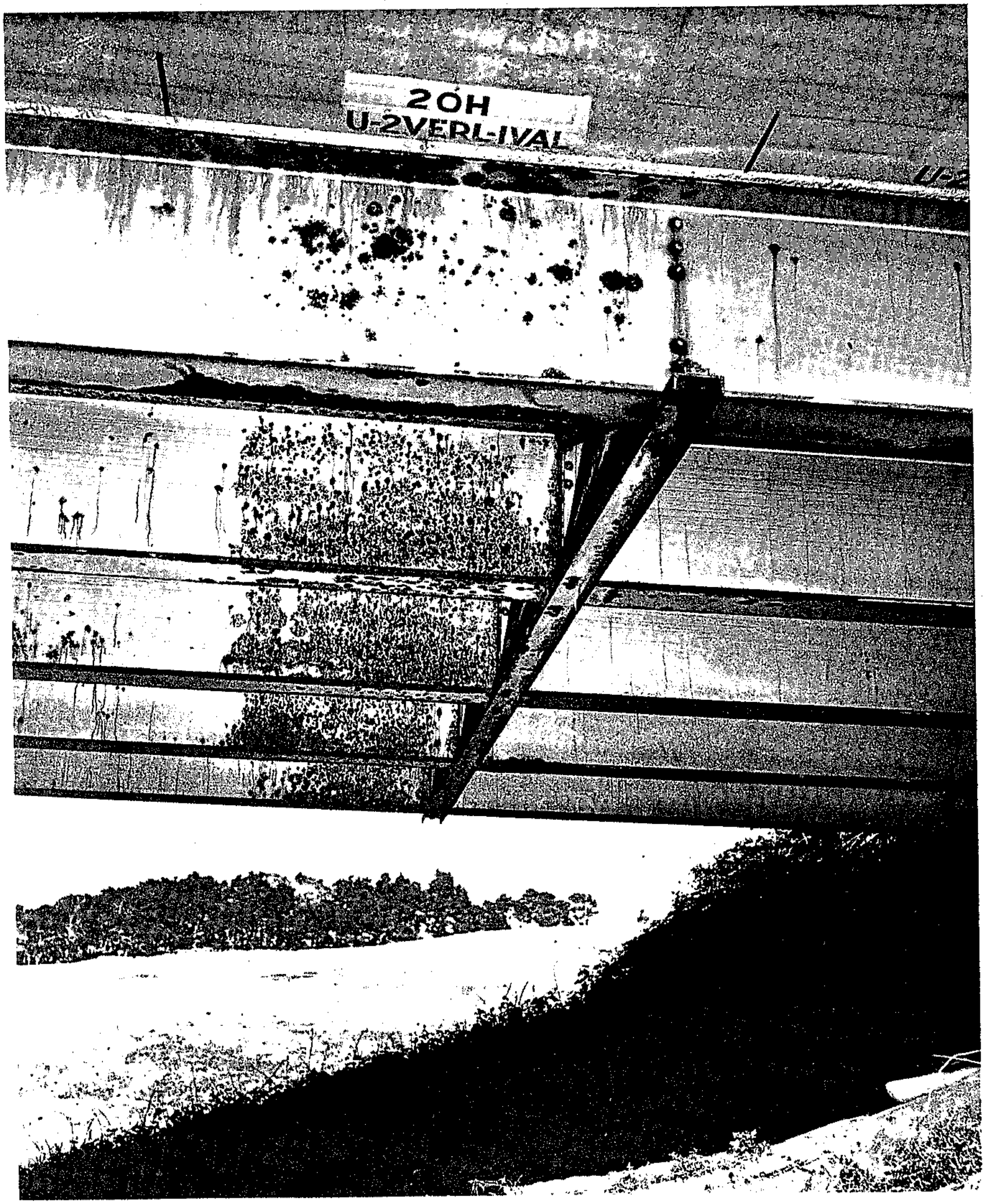


Fig. 17. The effect of the brace on corrosion areas is very marked in Panel 20H.

Fig. 18. Notice the vast improvement of the Red Lead Phenolic in Panel 21H over that shown in Fig. 11.

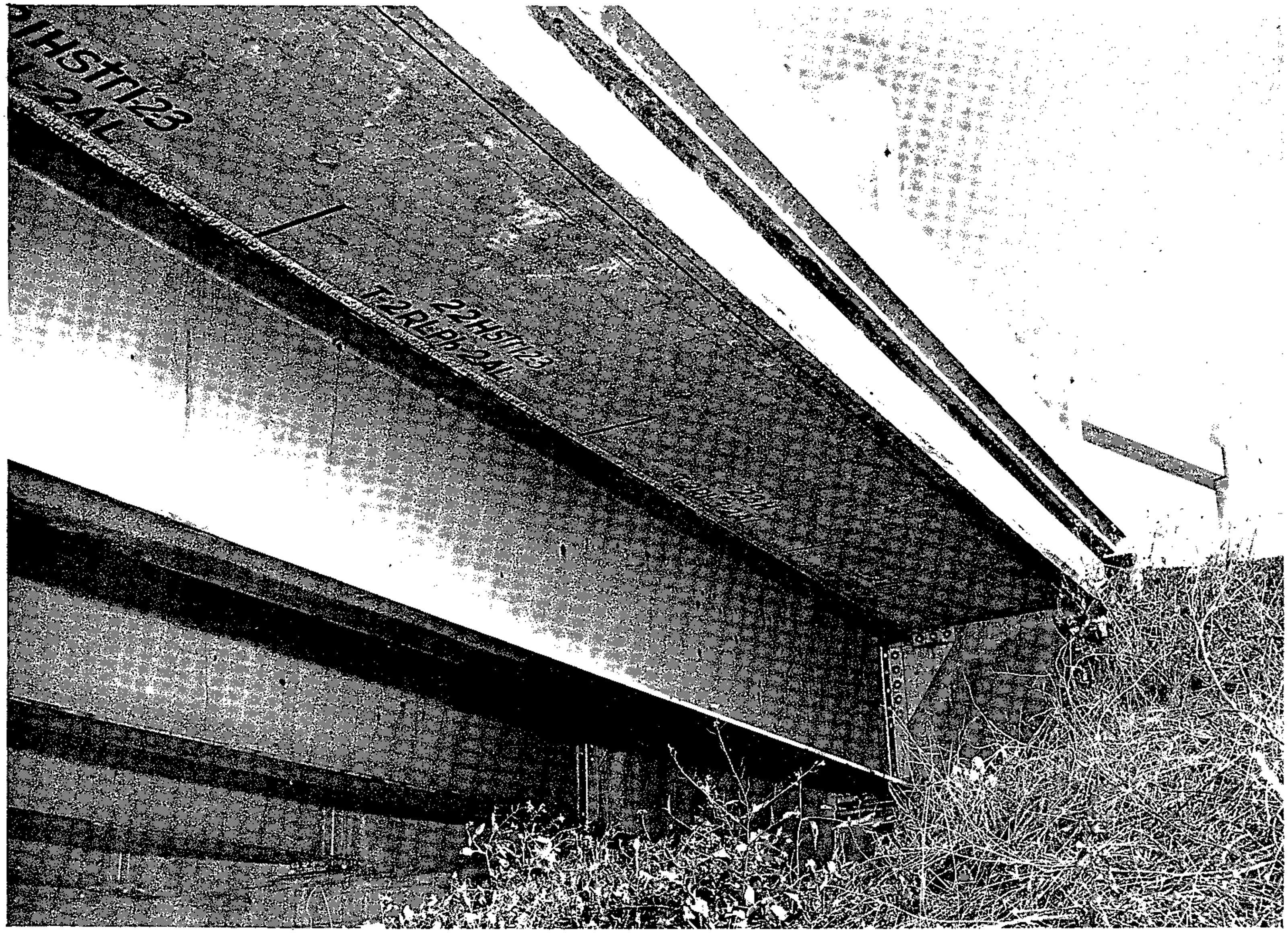


Fig. 19. The Red Lead Phenolics shown here in Panels 21H and 22H seem to have performed better than the old Red Lead and Metallic Lead formulation.

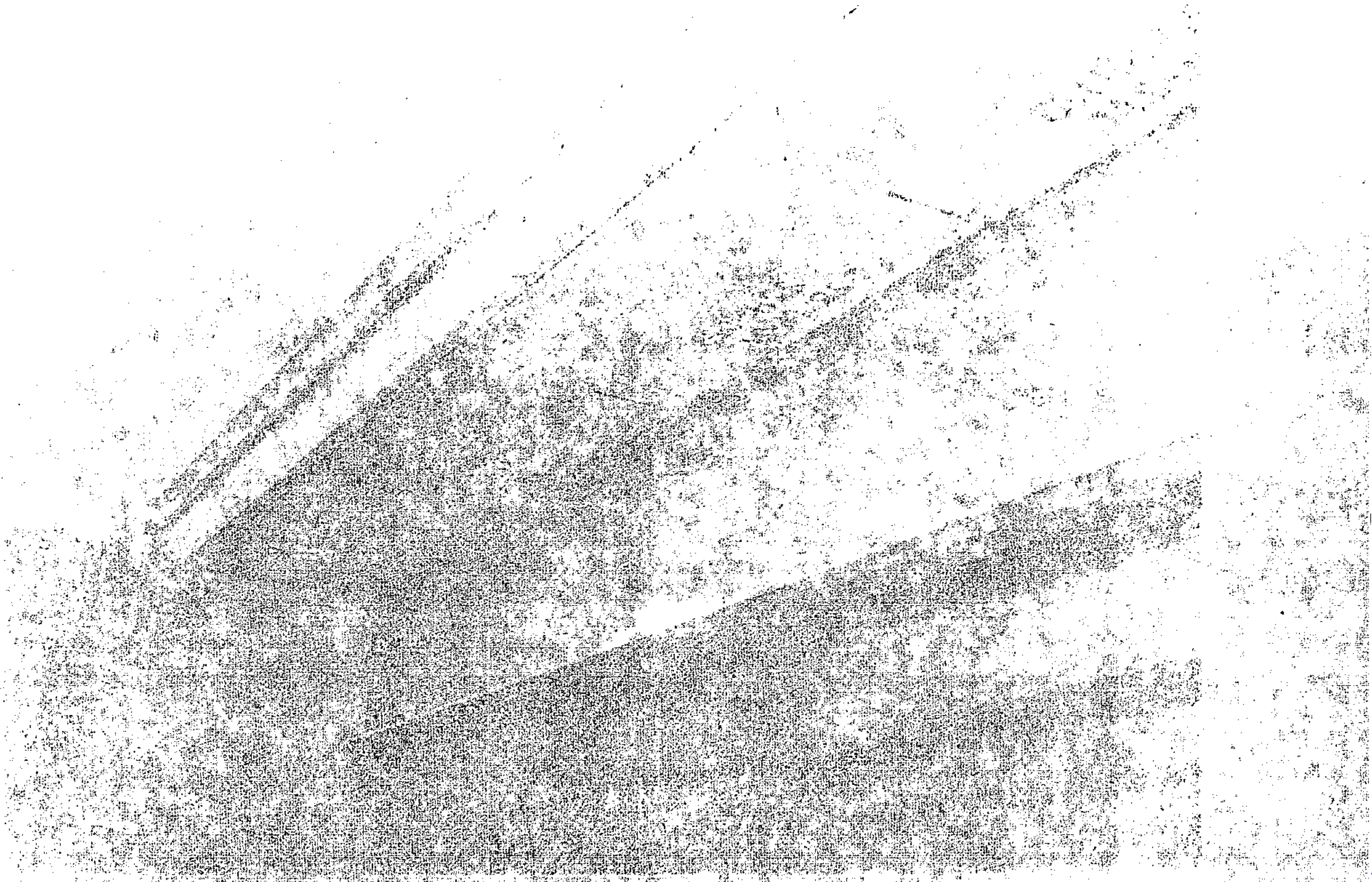


Fig. 15. The Red Head/Rheolith shown here at [illegible] and 22N seem to have performed better than the old Red Lead and Metallic Lead formulations.