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EVALUATION OF WEATHERING STEEL IN A DETROIT FREEWAY ENVIRONMENT
-SECOND EIGHT-YEAR STUDY-

MICHIGAN DEPARTMENT OF TRANSPORTATION

MATERIALS and TECHNOLOGY DIVISION

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Evaluation of weathering steel in a Detroit freeway environment : second eight-year study

EVALUATION OF WEATHERING STEEL IN A DETROIT FREEWAY ENVIRONMENT
-SECOND EIGHT-YEAR STUDY-

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Research Laboratory Section
Materials and Technology Division
Research Project 62 G-122
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Lansing, August 1986

INTRODUCTION

A cooperative study between the Michigan Department of Transportation (MDOT) and the Bethlehem Steel Corp. (BSC) was conducted between 1966 and 1974. This study was made to determine the differences in steel corrosion rates in an 'urban environment' and an 'urban highway environment.' The study concluded that the test panels were not performing as expected in a highway environment. This phenomenon was attributed to the location of the panels (the report constitutes Appendix A). Therefore, BSC suggested another study be performed to compare the urban environment (same exposure as the first study, a roof about 1/2 mile from the bridge), the poor highway environment (the southbound lanes of US 10, again the same as the first study), and a 'normal highway environment' (the northbound lanes of the same structure). The normal environment test site was located as far away as possible from the vertical retaining walls which were thought to be the cause of the poor performance of the steels in the first study (see Appendix B). The second study started in 1976, to date the two, four, and eight-year panels have been analyzed. This report is a summary of the information obtained to this time. The 16-year samples are still in place at the sites.

Procedure

Bethlehem Steel Corp. made the test racks, blasted, weighed, and measured the panels, and weighed the two and four-year exposed panels. Originally, all the Michigan Department of Transportation was to do was to provide the test site, provide traffic control, and remove the test racks at the appropriate intervals. In 1985 MDOT offered to analyze the data due to a large reduction in staff at Bethlehem's research laboratory (see Appendix C). Bethlehem agreed to this and provided the original panel information and the weights of the two and four-year exposed panels (see correspondence in Appendix D). The eight-year data and calculations are given in Appendix E.

There were seven different steels tested. (There were also some painted panels but they corroded so rapidly that the failure was probably due to the paint or its application - not the steel or its condition; therefore, the painted panels will not be addressed.) The seven steel types are:

1) 912 - Mayari R - ASTM A242, Type 1 — an architectural grade weathering steel.
2) 914 - Mayari R-50 — an experimental weathering steel.
3) 915 - C-guard — an experimental steel.
4) 916 - Copper-bearing steel — a reference steel.
5) 917 - Low-Sulfur, Aluminum-bearing steel — an experimental steel.
6) 919 - Plain Carbon steel - ASTM A36 — a reference steel.
7) 921 - Mayari R-50 - ASTM A588 — a structural grade weathering steel.

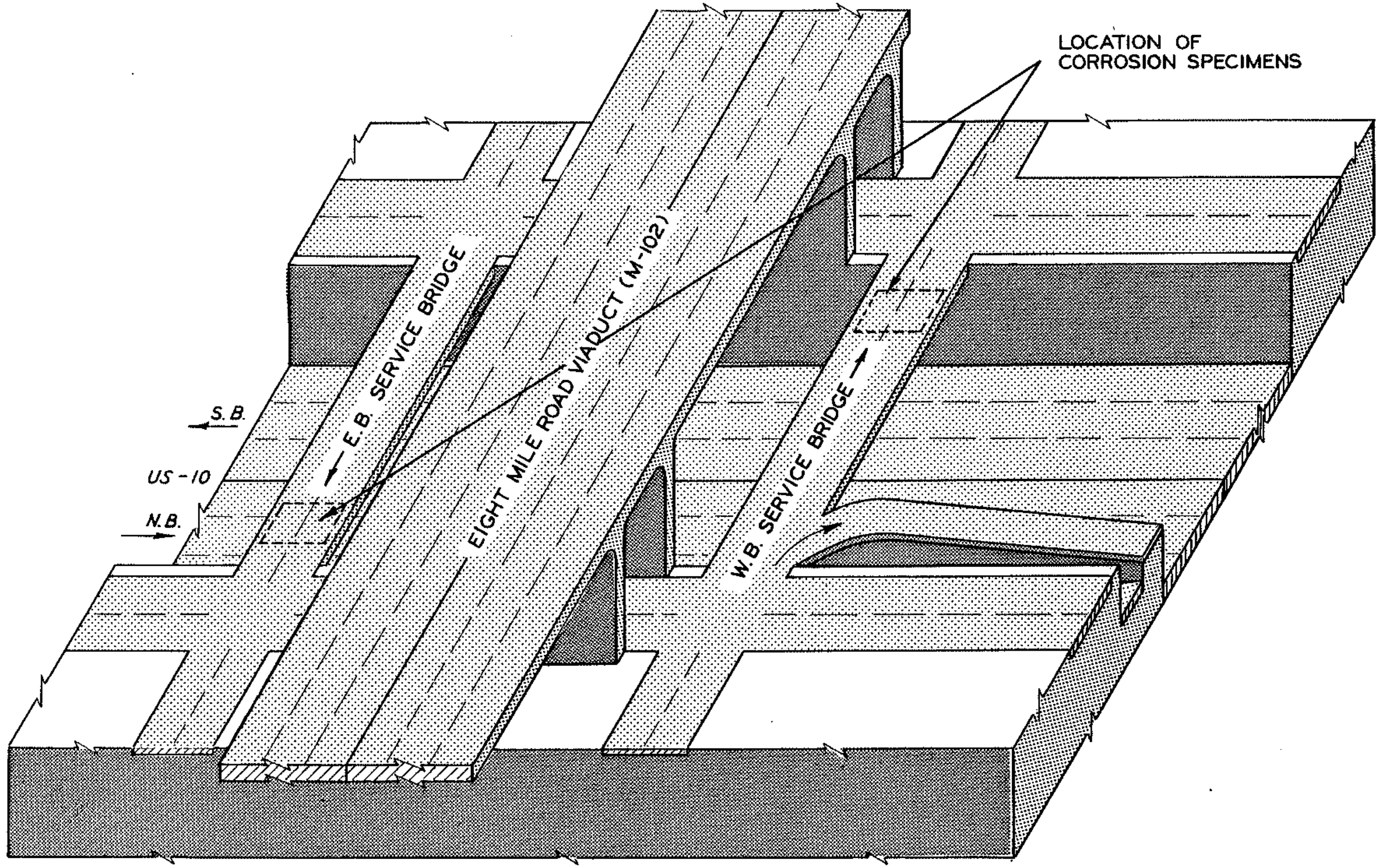

Figure 1. Complex intersection at the Eight Mile Road and the John Lodge Expressway; note location of corrosion specimens.

This report will deal only with the structural grade weathering, the plain carbon, the copper-bearing and, to a limited extent, the architectural grade weathering steels. The experimental steels were tested for BSC's information.

All panels were exposed at three locations. These were:

1) The roof of the National Guard Armory which is located about 1/2 mile from the bridge test sites.

2) On the westbound 8 Mile Rd service road bridge over Southbound US 10. These panels were about 15 ft from a vertical retaining wall (Fig. 1).

3) On the eastbound 8 Mile Rd service road bridge over US 10. These panels were close to the center of the structure far from the effects of a vertical retaining wall.

The procedure for examining the two and four-year panels was:

1) Remove panels,
2) Photograph racks and panels,
3) Record observations of panels,
4) Send the panels to BSC,
5) Remove the rust - ASTM G1.7.7.1 (Sodium hydride method), and
6) Reweigh panels.

The procedure was similar for the eight-year panel, except that the rust was removed according to ASTM G1.7.7.2 (Clark's solution). This was done with BSC's assurance that both methods produced similar results.

A pit depth study is in progress on the eight-year panels. These panels were chosen because the history is well documented and the surfaces after corrosion varied a great deal. This study has grown to such magnitude that it will be reported separately. Only the observations will be discussed in this report.

Observations

1) The bridge-exposed panels were covered with a loose flaky corrosion product at both exposure sites and at all three exposure times.

2) The general corrosion rate of the first test (1966 to 1974) was higher than the general rate in the second test. (The general rate is the averaged rate of all steel types at all sites over the zero to eight-year interval.)

3) The corrosion rates of the roof exposure (bold exposure) are much lower than the bridge exposure (sheltered) for all time periods.

4) The most severe exposure site was the location above the southbound traffic lanes, close to a vertical retaining wall.

5) The least severe site was the roof exposure where all the panels, including the plain carbon steel, corroded less than any of the steels exposed at the bridge.

6) At the same exposure site, in no case was there a corrosion resistance factor of 4 as determined by any method between the plain carbon and the A588 steels.

7) At the same exposure site in no case was there the required factor of 2 difference between the copper-bearing and the A588 steels (at only the northbound site did the A242, Type 1 achieve a factor of 2).

8) At all sites the corrosion rate ratio of plain carbon to copper-bearing steel was 1.45 (using the four to eight-year time interval).

9) At all sites the corrosion rate ratio of A588 to copper-bearing steels was 1.24 (using the four to eight-year time interval).

10) The appearance of the various cleaned steels varied greatly both with respect to environment and type:

a) at the bridge site the top surface was more deeply pitted than the bottom for the A588, copper-bearing and plain carbon steels,

b) at the roof site the pitting was about the same on the top and bottom for the A588, copper-bearing and plain carbon steels, and

c) the A588 and copper-bearing steels had about the same pit depth as the plain carbon but the diameters of the pits appeared to be much smaller and the frequency much higher.

DISCUSSION

The discussion will consist of the following sections:

1) Exposure conditions and comparisons,
2) Corrosion resistance factors,
3) Comparison of the first and second study at 8 Mile Rd, and
4) Future testing.

Exposure Conditions and Comparisons

All test panels were placed at the roof exposure site on December 17, 1976. This allowed all the panels to form an initial rust layer in a mild environment similar to expected exposure conditions for a bridge structure. (See correspondence in Appendix F.) On June 29, 1977 the bridge exposure panels were transferred to the bridge site. The problem with this procedure is determining what date to use as an initial starting date to generate a corrosion rate curve. To overcome this the rates for both methods were calculated. The corrosion loss for the roof environment was assumed to be linear for the first time interval, zero to two years (this is known to be untrue but since it is on the conservative side and better than no correction factor, the assumption was used). The corrosion loss during the common roof exposure was then subtracted from all exposures and the site exposure date of June 29, 1977 could be used as a starting point. The difference this makes can be seen by comparing the rates listed in the data tables under column headings YAML and SITE (code is in Appendix E, Table 1). This will not affect the four to eight-year interval.

All comparisons are made only between the A588, copper-bearing, and plain carbon steels. (The A242, Type 1 will also be listed in the tables since this is the only weathering type that was tested in the first eight-year study. It will be necessary for any comparisons in Section 3.) The results of the tests are presented in Figures 2 thru 8.

There are large differences in the corrosion rates at the various environments. The sheltered bridge environment corrosion rates are approximately 3.5 and 7 times greater than the boldly exposed roof environment for the northbound and southbound bridges, respectively. Since the corrosion rate for various environments is usually expressed as a function of a boldly exposed plain carbon steel (A36), and it is the industry standard to paint boldly exposed plain carbon steel in an urban environment, a comparison of the corrosion rates of the various steels and environments to the roof-exposed plain carbon is appropriate. The A588 bridge-exposed panels over the northbound lanes corroded at least 2.5 times faster than the roof-exposed plain carbon panels. The copper-bearing steels all corroded approximately 4.5 times faster. The plain carbon bridge-exposed steels corroded 4.8 times faster. If the corrosion rate is greater than that of roof-mounted plain carbon steel, does the steel need to be painted? Although this information is of interest, and it aids in determining the necessity of painting, it is more important to know the effects of the localized corrosion rate on the structural integrity of the steel. This will be further discussed in the next two sections.

The appearance of the corroded steel is another important characteristic since most people judge the functionality of the steel by its appearance. Many base their judgments that the steel is performing well on the fact that it looks good. In reviewing the recorded observations, it looks as though appearance and corrosion rate are independent variables. The environment has a much more dramatic effect on appearance than does the corrosion rate. The appearance of both bridge exposures exhibited loose flaky rust and dirt, yet the corrosion rates varied by a factor of 2. The roof exposure of even the plain carbon steel looked good, i.e., it had a tight adherent rust layer; but its corrosion rate was 1.8 times that of the A588 steel (which also had a tightly adherent rust layer). From these observations it is concluded that appearance and corrosion rates can be compared only in the broadest sense. Since non-weathering steels form protective rust layers (i.e., layers of corrosion that reduce corrosion rates) when boldly exposed in many environments, and appearance is more dependent on environment than on corrosion rate, appearance is not a good criterion to determine the functionality of the steel.

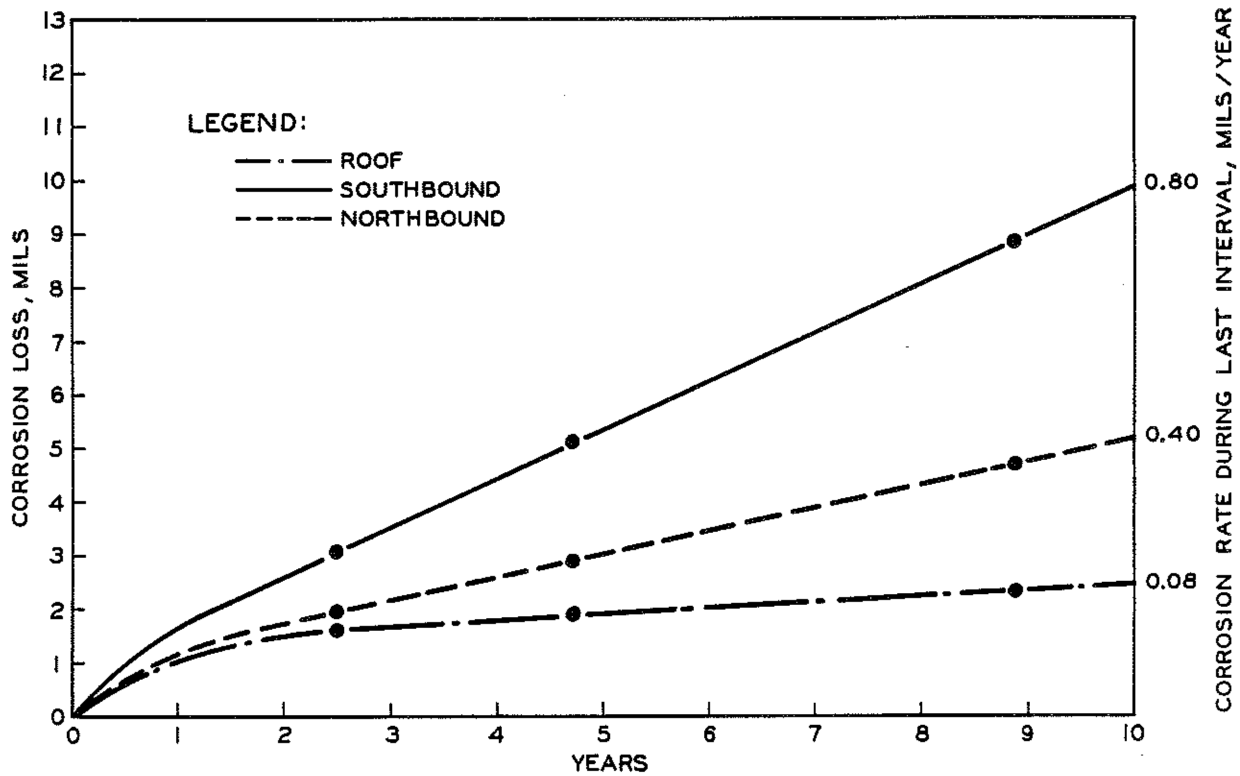

Figure 2. Corrosion curves from the second 8-Year study for A588 at all exposure sites.

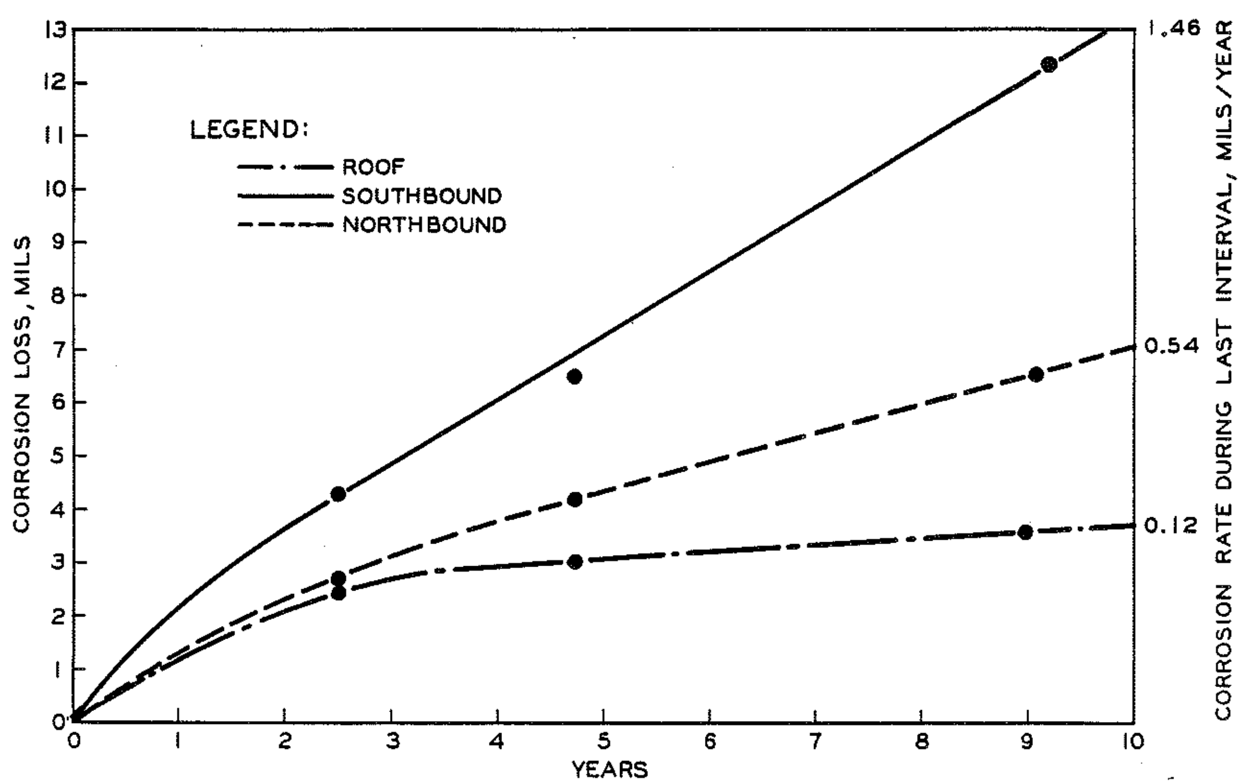

Figure 3. Corrosion curves from the second 8-year study for A36 at all exposure sites.

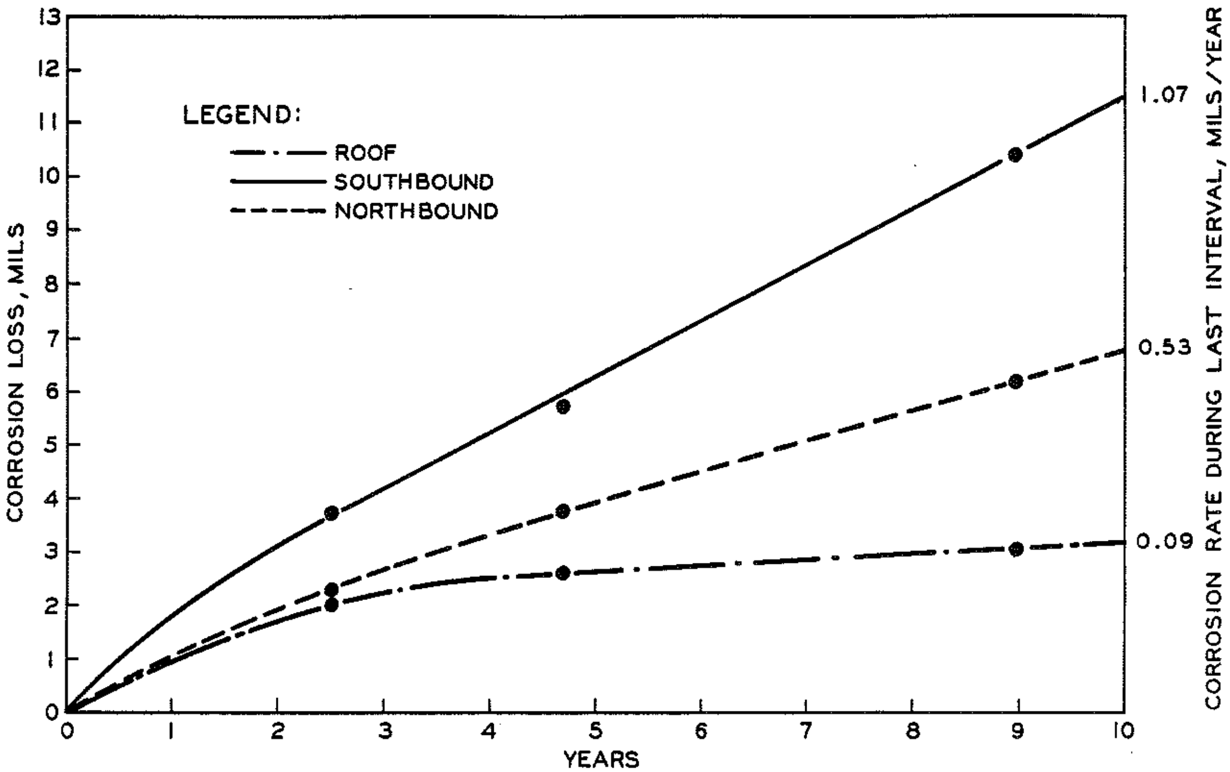

Figure 4. Corrosion curves from the second 8-year study for Copper Bearing at all exposure sites.

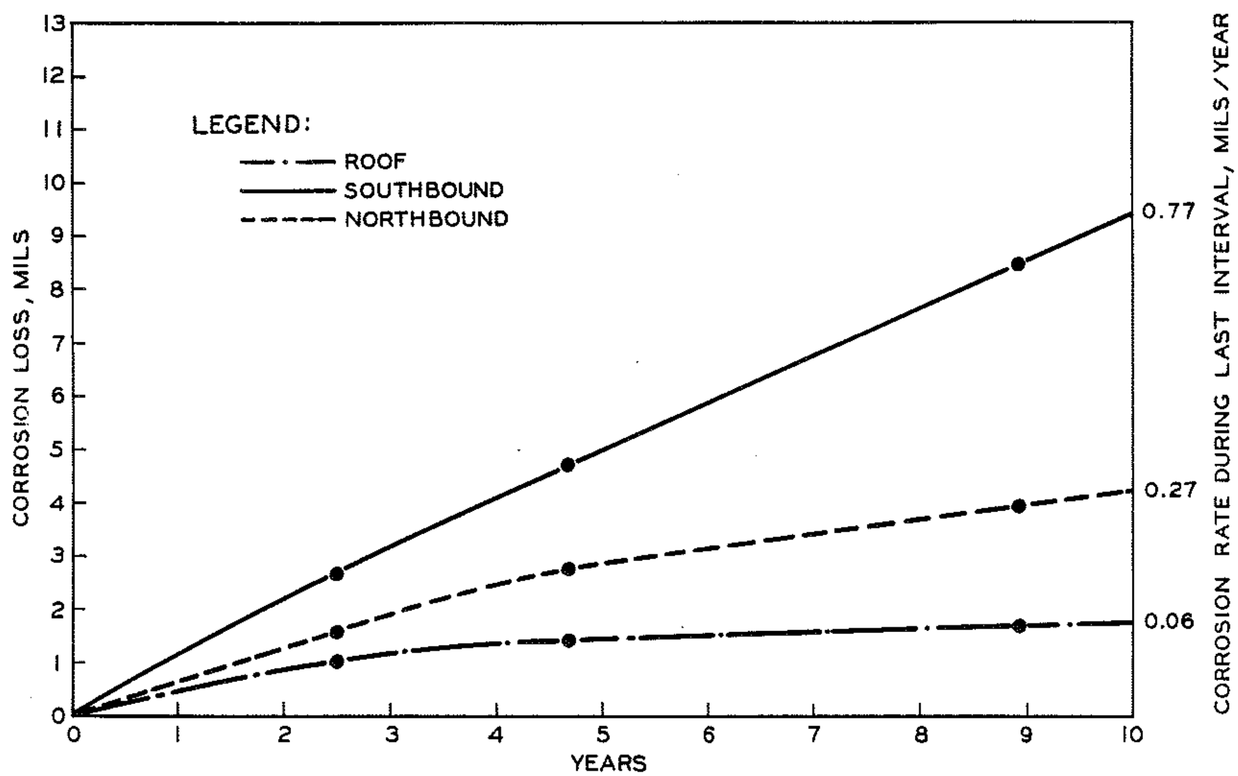

Figure 5. Corrosion curves from the second 8-year study for A242, Type 1 at all exposure sites.

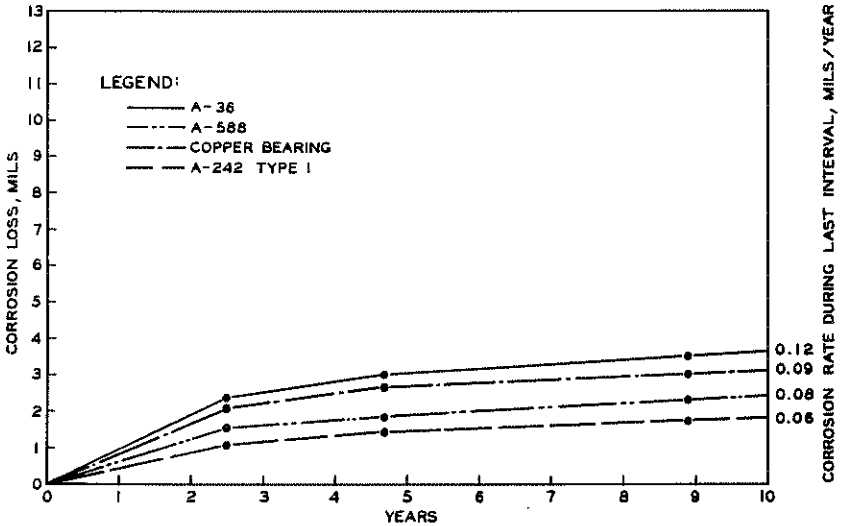

Figure 6. Corrosion curves from the second 8-year study for all steels at the Roof exposure site.

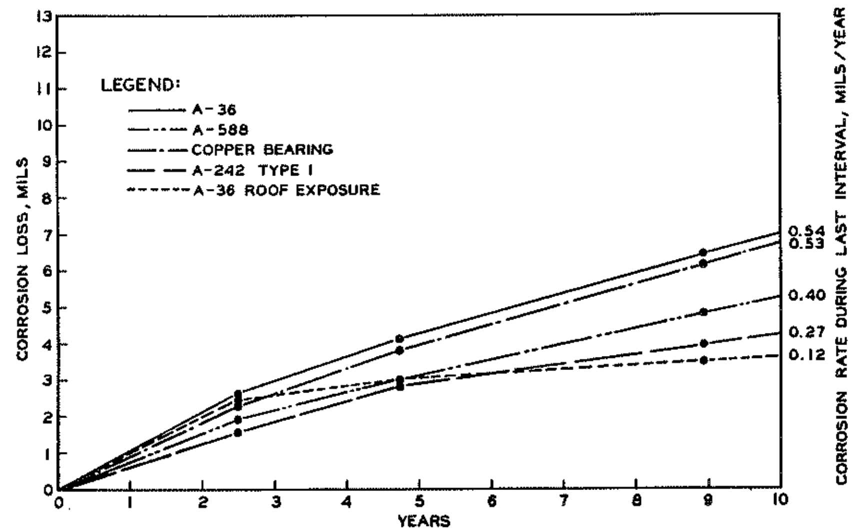

Figure 7. Corrosion curves from the second 8-year study for all steels at the Northbound exposure site.

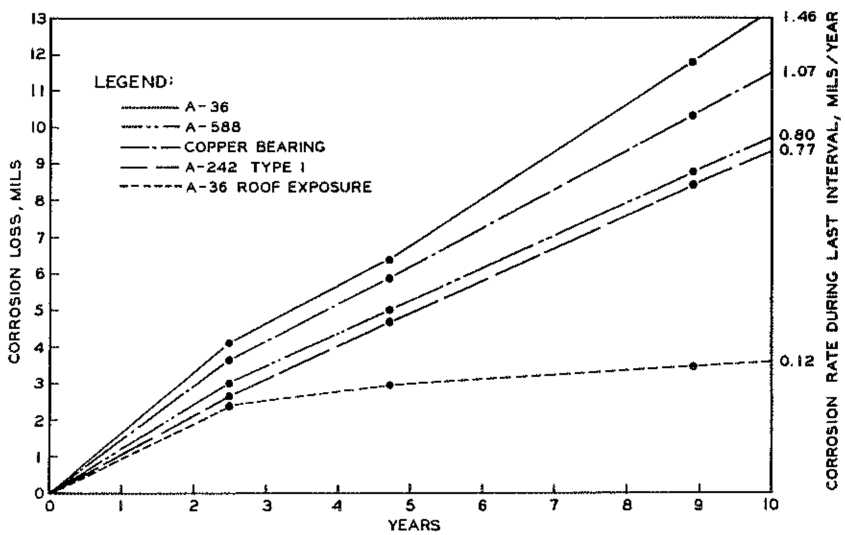

Figure 8. Corrosion curves from the second 8-year study for all steels at the Southbound exposure site.

Corrosion Resistance Factors

There are basically three different methods of comparing corrosion resistance (1).

1) A corrosion rate comparison between A588 and other steels (corrosion factors).

2) A comparison of the effects of corrosion on the physical properties of the steels.

3) A comparison of the time it takes to reach a given level of corrosion.

The first method is the most common and the oldest. Originally A588 steels were said to have four times the corrosion resistance (i.e., 1/4 the corrosion rate) of plain carbon steels. When the ASTM specification was adopted it was decided to use two times the corrosion resistance based on corrosion rates of copper-bearing steels and assume the corrosion resistance of copper-bearing steels to be twice that of plain carbon steels. This is not the case here as the average of the corrosion rate ratios for all sites is 1.2 for the four to eight-year interval. To date, little data have been found, particularly in chloride environments, to support the two-times superiority of copper-bearing steels. However, as can be seen in Table 1, even if the assumption were true, the A588 steels did not have the required two-times corrosion resistance as stated in the A588 specification. Comparing A588 steels to either plain carbon or copper-bearing steels in a given environment will generate a corrosion factor, but these factors are dependent on the corrosivity of the environment; therefore, the factor and the effects of corrosion are unrelated. This being the case, the corrosion factor determined by this method is useless to the specifying engineer.

TABLE 1
CORROSION FACTORS CALCULATED ASSUMING
A LINEAR CORROSION RATE AFTER FOUR YEARS

Environment	Time - Years to loss of 20 mil Weight Equivalent				Ratio of Times			
	A588	Plain Carbon	Copper Steel	A242 Type 1	A588 to Plain Carbon	A588 to Copper Bearing	Copper to Plain Carbon	A242 to Plain Carbon
Roof	238	134	192	330	1.8	1.2	1.4	2.4
Southbound	20	14	16	26	1.4	1.3	1.1	1.8
Northbound	52	28	30	74	1.9	1.7	1.1	2.6
				Average	1.7	1.4	1.2	2.3

The second method for determining a corrosion factor is to compare the physical properties of the steel as they are affected by corrosion. There has been very little work published in this area. The only work found was that of J. Raska of the Texas Department of Transportation, who exposed tensile specimens and compared corrosion weight loss to reduction in ultimate tensile strength. The loss in ultimate strength was much greater than that which would have been predicted based on corrosion losses as determined by weight loss (the most common method) but it will be difficult to relate the results from one environment to another without a great deal of testing. The extent of this testing is so massive that it is well beyond the economic capabilities of the Department.

The third method is recently gaining popularity with the steel companies. In a paper by Townsend and Zoccola, both of BSC, they discuss the problem of comparing factors and effects on the engineering properties of the steel (2). They suggest that the time to a certain level of corrosion is a better method for comparison. The paper assumes a decreasing corrosion rate with time after eight years. Since we can find little data to support this position, it is exactly the opposite of the same authors opinion in the first eight-year study (Appendix A), and the literature (3) indicates that the corrosion rate is constant; our comparison, based on the four to eight-year corrosion rate, seems more appropriate. The paper also assumes that a 20 mil (10 mils each side) loss of section is significant. The times to 20 mils of corrosion are listed in Table 1, along with the ratios of the times (since we assumed a constant rate after four years the ratio of the times is the same as the ratio of the rates). It can easily be seen that the effect of the variation in the environment is much greater than the variation in ratios. Since the test sites are within 1/2 mile of each other it can further be stated that the times are dependent on the local environment or site environment. Thus, this method is applicable only to a given site. It should further be noted that in no case was a corrosion resistance of four times that of plain carbon steel achieved. This method is site-specific and can lead to extremely long-life projections, in some cases based on a testing period that is less than 3 percent of the anticipated life. It does, however, tell the engineer something of the product's characteristics if one does not convert years to 20 mils of corrosion to the ratio of the times to 20 mils of corrosion and if the effects of 20 mils of corrosion on the engineering properties are well documented. The first condition is easily met, the second will require years of research — again, well beyond the capacity of the Department.

In summary it appears that the current methods for determining corrosion resistance factors are inadequate and their use questionable. A great deal of information and improvement will be necessary before this steel can be specified with certainty in a given environment.

Comparison of the First and Second Study

The first study was started in 1966 and completed in 1974. The results of this study are summarized in a letter in Appendix A. Table 2 compares the portions of the data that are the same in both tests; i.e., the roof and southbound exposure sites, the horizontal top and bottom exposures, and the plain carbon and A242, Type 1 steels. (It should be noted that there are a number of sources that indicate the superiority of A242, Type 1 over

TABLE 2
COMPARISON OF THE FIRST AND SECOND EXPOSURE TESTS AT US 10 AND 8-MILE ROAD DURING THE LAST FOUR-YEAR INTERVAL*

Environment	Loss at the Beginning of the Four-Year Test Period, mils		Loss at the End of the Four-Year Test Period, mils		Loss During Four-Year Test Period, mils		Corrosion Rate mils/year**		Corrosion Factor
	A242	Plain Carbon	A242	Plain Carbon	A242	Plain Carbon	A242	Plain Carbon	
Roof									
First Test	3.71	5.48	4.84	9.13	1.13	3.65	0.24	0.78	3.25
Second Test	1.37	3.03	1.69	3.6	0.32	0.57	0.08	0.14	1.75
Southbound									
First Test	5.03	7.79	17.82	17.75	12.79	9.97	3.13	2.44	0.78
Second Test	5.18	6.45	8.51	12.69	3.33	6.24	0.81	1.51	1.86

* For comparison purposes it is necessary to use the 2.92 to 7 year interval for the first test and the 4.79 to 8.92 data for the second test.

** Time intervals are 4.08 years for first test and 4.13 for the second test.

A588 steels. Thus, if A242, Type 1 is not performing, A588 will be worse.) In general, the average corrosion rate of all samples is much greater in the first study than in the second. No explanation can be offered. Although the corrosion rates are lower in the second study they are not low enough. The times to significant losses (20 mils) are much shorter than most structures' design lives.

Future Testing

Based on the two eight-year studies and the Michigan experience in general, there is a need to better understand the results of corrosion on weathering steels. This section will highlight some of the uncertainties of weathering steels. Due to the magnitude of the uncertainties the steel should still be considered experimental.

1) The Boldly Exposed Environment - There is inconsistency in the literature as to what a bold exposure is. Some say exposed to the washing of the rain and drying of the sun, while others simply say exposed to the elements. This is a big difference especially when considering a bridge. In one case the bridge is boldly exposed, in the other it is not.

The rates of corrosion in some boldly exposed environments are well documented. The rate of corrosion which mandates whether or not to paint a structure is not the corrosion rate in a boldly exposed environment. It is more important to know the effects of sheltering, crevices, orientation, electrolyte, etc., on the rate. Unfortunately, these are not well understood. For example, if two steels have corrosion rate ratios of 4 in a boldly exposed environment (typical of a corrosion test site), will they also have a ratio of 4 in a sheltered area, in a crevice or in a chloride environment (conditions typical of a bridge)? Current documentation is very weak. Current observations would indicate that there are major differences in both the rates and the ratios depending on exposure conditions.

2) The Effects of Corrosion on Engineering Properties - The use of general corrosion rates of test panels has been used in the past to demonstrate the long-term effect of corrosion on strength. A good example of this is contained in the first eight-year report (Appendix A). The report states "...calculations indicate that with an average corrosion rate of 1.25 mils per year, the initial thickness and strength of the beams, and the design submitted by the Michigan State Highway Department, the structural capacity of the bridge would still exceed the maximum strength requirement by about 20% after 75 years of service."

If one were to make the same assumptions, use the corrosion rates (1.25 mils/year) in the first report (the higher of the two reports) and an equal original design strength using A36, the bridge would exceed the maximum strength requirement by about 43 percent after 75 years of service. In other words, the unpainted A36 bridge would be better than an unpainted A588. It is well known that an unpainted A36 will not last 75 years. The effects of localized corrosion cells are much more important than general corrosion rate on strength (same problem as described in the bold exposure section).

Very little is known of the effects of corrosion, general or localized, on yield strength. A great deal of effort should be directed toward this problem. (It should be noted that while yield strength is an important engineering property, fatigue life may be affected to a much larger degree. There are a number of agencies working in this area.)

3) The Effect of Mill Scale - In both of these studies (or in any study we have found to date) the effects of mill scale is not one of the variables. It is thought that the mill scale will weather off. In blasting a 13-year-old urban structure from which the mill scale had not been removed originally, it was observed that the mill scale did not weather off. In fact, a layer of corrosion was over the mill scale and the areas adjacent to the mill scale were corroding rapidly (3 mils/year). Although more work should be done it appeared that the weathering-off of the mill scale depended on the thickness of the member, the time of wetness, and electrolyte strength.

4) The Effects of Time of Wetness - The time of wetness is generally considered a factor of the environment. It can be greatly affected by design. A good example of this is the inside of light poles. The problem is not the rate of corrosion on the outside of the pole but on the inside. Moisture tends to collect in the debris on the inside of the pole at the base. In a known case of failure the pole corroded from the inside out. To date there have been no studies found comparing time of wetness to corrosion rate on weathering steels.

CONCLUSIONS

1) The corrosion rate in a sheltered urban highway environment is much higher than a boldly exposed urban environment.

2) Corrosion factors vary significantly from environment to environment.

3) The use of corrosion factors is meaningless. They tell the engineer nothing of the effects of corrosion on the properties of the steel or the rate of corrosion.

4) The use of the amount of time to a given level of corrosion is useful only if no comparisons are made between two steels, the test site is the same as the structure site, and if the effects of corrosion at the given level are clearly understood.

5) The appearance and the corrosion rate are only to be related in the broadest sense. No engineering judgments should be based on appearance.

6) The steel should still be considered experimental since:

a) The relationships between corrosion factors (or rates) of boldly exposed steels and other types of exposure (i.e., crevices, sheltered, chloride, and time of wetness) are not documented for weathering steels,

b) The effects of corrosion on the engineering properties are not well documented,

c) The effects of mill scale are not well documented, and

d) There is a great deal of conflicting opinion in the literature even among the producers.

7) If used in northern climates where salt is used the steel should be painted.

REFERENCES

1. Albrecht, P. and Naeemi, A. H., "Performance of Weathering Steel in Bridges," NCHRP Report No. 272, Transportation Research Board.

2. Townsend, H. E. and Zoccola, J. C., "Eight-Year Atmospheric Corrosion Performance of Weathering Steel in Industrial, Rural, and Marine Environments," Atmospheric Corrosion of Metals, ASTM STP 767, S. W. Dean, Jr. and E. C. Rhea, Ed., American Society for Testing and Materials, 1982, pp 45-59.

3. Metals Handbook, Ninth Edition. Volume 1, Properties and Selection: Irons and Steels. American Society for Metals, Metals Park, Ohio.

APPENDIX A

Bethlehem Steel Corporation

BETHLEHEM, PA. 18016

J. G. WHITE, JR.
GENERAL MANAGER OF SALES
J. D. CUMMINGS
J. B. DOUGHERTY
ASST. GEN. MANAGERS OF SALES

BETHLEHEM STEEL

SALES ENGINEERING
S. E. CHEHI
MANAGER
I. M. VIEST
R. F. WELLNER
ASSISTANT MANAGERS

April 12, 1976

Mr. K. A. Allemeier, P.E.
Engineer of Testing & Research
Department of State Highways
and Transportation
Lansing, Michigan 48904

Dear Mr. Allemeier:

Enclosed is the report of corrosion tests conducted at the Eight-Mile Road Interchange near Detroit. The report serves to update with 8-year data the more detailed report which was previously written based on 4-year tests.

This work shows that where boldly exposed and subjected to normal washing and periodic drying, Mayari R (ASTM A242): (1) develops an adherent protective rust layer, (2) exhibits corrosion rates which decrease with time, and (3) as expected has (at least) 4 times the corrosion resistance of carbon steel. Most of the bridge surfaces behave in this manner. However, in the tunnel-like confined areas next to a solid wall beneath the westbound service bridge where road salts and dirt accumulate on the surface of the steel, we observe that Mayari R: (1) develops a flaking, non-protective rust layer, (2) exhibits relatively high corrosion rates which do not decrease with time, and (3) behaves much like carbon steel.

We suggest that the test program be extended to enable continued monitoring of the performance of Mayari R at this location. At the same time, we could test the effectiveness of remedial measures, such as paint coatings, which could be employed in the event that such measure should become necessary. If this approach is acceptable, our Research Department will work out details of the program with the Michigan State Highway Department.

Very truly yours,

BETHLEHEM STEEL CORPORATION

Stephen E. Chehi

Manager, Sales Engineering

SEC:mza

Bethlehem Steel Corporation

BETHLEHEM, PA. 18016

April 12, 1976

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INTER-OFFICE CORRESPONDENCE

BETHLEHEM STEEL

April 5, 1976

FILE REF. 1801-le
TZ-34-75019

FROM J. C. Zoccola, Engineer, Corrosion Mechanisms

TO H. E. Townsend, Supervisor, Corrosion Mechanisms

SUBJECT CORROSION RESISTANCE OF MAYARI R STEEL ON THE EIGHT-MILE ROAD BRIDGES AT DETROIT, MICHIGAN

Ref. (1) G. F. Melloy to R. E. Simpson, June 2, 1970, 1801-le.
(2) J. W. Frame to R. E. Simpson, April 30, 1971, 1801-le.
(3) J. B. Horton to S. E. Chehi, June 4, 1974, 1801-le.

Introduction and Summary

In cooperation with the Michigan State Highway Department (MSHD), we have completed our investigation of the corrosion resistance of Mayari R steel on the weathering steel bridges at the complex interchange of the Eight-Mile Road and James Couzens Expressway at Detroit, Michigan.

The Eight-Mile Road Bridges have been opened to traffic for about 9 1/2 years. Corrosion specimens were exposed for 8 years in the tunnel-like underpass of the Westbound Service Bridge above the southbound lanes of the expressway. For comparison, identical specimens were also located on a nearby building roof free of traffic fumes, road spray, dirt, deicing salts and other deposits. The objective of the test was to determine the effect of road dirt, salts and the like on the corrosion resistance of weathering steels (ASTM A242).

Major portions of the Mayari R steel on the bridges over the expressway, as well as the corrosion specimens on the roof of the building, are showing the pleasing, uniform protective-oxide layer characteristic of weathering steels. However, Mayari R beams on the low-level service bridges above the southbound lanes of the highway, and the 8-year specimens on these beams are not performing well. There is heavy flaky rust and considerable road salts and soil on these surfaces. Corrosion-rate measurements on the 8-year panels confirm previously reported 4-year indications (References 1 and 2) that appreciable corrosion is occurring at these areas. Corrosion is about 1.23 mils per year and increasing with time of exposure in contrast to 0.28 mil per year and corrosion decreasing with time for specimens on the nearby building roof free of traffic fumes, road salts and dirt. There was no significant pitting beneath the scaly rust, nor any significant accumulation of deposits or flaking rust on the steel members in the relatively unconfined sections of the service bridges over the northbound lanes of the expressway.

The poor behavior of the Mayari R steel is due to an accumulation of road dirt and salts on the steel surfaces. There is a high retaining wall along the shoulder of the depressed highway beneath the low-level service bridges and tunnel-like conditions in the underpass next to the wall. These conditions intensify the air blast created by the heavy traffic on the expressway and carry road spray, dirt, and salts to the steel surfaces. The deposits tend to keep the surface wet and keep chlorides and sulfates in close contact with the steel and cause an accelerated poultice-type corrosion.

Results of the test clearly show the importance of periodic wetting, rain washing and drying for the development of protective rust on weathering steels and the need to be wary of tunnel-like underpasses and conditions that allow road salts and dirt to accumulate on the steel surfaces. Sales Engineering calculations (Reference 3) indicate that, with an average corrosion rate of 1.25 mils per year, the initial thickness and strength of the beams, and the design data submitted by the MSHD, the structural capacity of the bridge would still exceed the maximum strength requirement by about 20% after 75 years of service. In this calculation, the recently adopted AASHTO* Load Factor Design Criteria and load factors supplied by MSHD were used. However our data (see Figure 2) indicate that the corrosion rate in the confined regions may be increasing with time. We don't know whether this is a long-term trend or due to a short-term change in environmental conditions.

Test Procedure

We had installed 4- x 6-inch Mayari R steel panels on the weathering steel beams of the Westbound Service Bridge, in a vertical position to simulate the beam web and horizontal-top and horizontal-bottom to parallel the beam flanges. As a comparison, specimens were also located on the roof of a nearby building, free from road spray, salts and soil. In a second test, started later, plain carbon steel and Mayari R steel were placed at both sites. Table 1 shows the composition of the steels.

There are 3 bridges at this complex interchange; two low-level service bridges, westbound and eastbound, with a high-level viaduct in between. Mayari R structural beams or plates support the bridges. Reference 2 describes and illustrates by colored photographs the location and condition of the bridges and specimens since our last inspection. Specimens were exposed in a relatively confined, tunnel-like area above the southbound section of the James Couzens Expressway** having a high, concrete retaining wall on one side and concrete

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* American Association of State Highway and Transportation Officials.

**The James Couzens Expressway was erroneously referred to in previous correspondence as the John Lodge Expressway. The two expressways are one continuous highway but the section away from Detroit and beneath the bridges is known as the James Couzens Expressway.

abutments on the other. The sections above the northbound lanes, however, are relatively open (no solid wall) and there is an adjacent exit and entrance ramp that slows down traffic and allows greater dissipation of road spray. The service bridges have a clearance of about 14 1/2 feet above the expressway.

Discussion and Results

A comprehensive report (Reference 1) and a paper (Reference 2) on our test of Mayari R steel at Detroit, Michigan were written after the 4-year removal of specimens beneath the bridge beams and an inspection of the bridges after 5 1/2 years of service. These reports included X-ray diffraction and chemical analyses of the soil and rust, as well as comparative studies of corrosion rates on the steel specimens and photographs of the various sections of the bridges and of the specimens. The paper in Reference 2 was sent to each of the state highway departments. This last removal of specimens and inspection was only to determine if conditions continued to progress in similar fashion to that of the 4-year removal and inspection.

The corrosion performance of Mayari R steel has not significantly changed since our last removal of panels and inspection of the bridges (Reference 3). The major proportion of the Mayari R steel on the bridges above the expressway, as well as the 8-year corrosion specimens on the building roof, continued to exhibit excellent performance, having a uniform, pleasing, protective rust layer after 9 1/2 years of service. However, there is still heavy scaling and flaking rust, with continued accumulation of road dirt and salts on the Mayari R beams of the two underpasses of the service bridges above the southbound lanes of the expressway, and on the 8-year corrosion specimens in one of the underpasses. Apparently tunnel-like conditions in these areas intensify the air blasts from the heavy traffic flow on the expressway. The turbulent air carries appreciable road spray, salts and dirt to the weathering steel beams and specimens in the underpasses. The possible source of the salts and soil are listed in Table 2.

An analysis of the soil (Table 3) accumulated during a 4-year period on the painted corrosion rack shows appreciable amounts of chlorides and sulfates which are known to accelerate corrosion of steel.

Eight-year corrosion specimens were removed from corrosion racks on the Westbound Service Bridge and nearby National Guard Armory Roof for inspection, determining corrosion losses and for chloride analyses of the intermingled rust and soil on the panels. Figure 1 illustrates the appearance of specimens on painted corrosion racks. As on the 4-year panels, the 8-year specimens on the bridge continue to show flaking rust, a high corrosion rate (average of 1.23 mils per year) with corrosion increasing with time of exposure, while those on the Armory Roof have a uniform, tight protective rust layer, a low corrosion rate (average of 0.28 mil per year) with corrosion decreasing with time of exposure, cf. Tables 4 and 5 and Figures 2 and 3. As expected, the horizontal-top panels on the bridge, when there is greatest accumulation of solids, show the most corrosion.

The thickness of some of the undisturbed, intermingled rust-soil layer on the 8-year bridge panels was measured and analyzed for chloride content. The rust-soil layer was from 55 to 65 mils thick, about double that on the 4-year specimens, which was 25 to 35 mils thick. The surface underlying the flaky rust layer was relatively smooth and free of pits.

The accumulation of chlorides on the surface of the bridge panels over the 8-year period is shown in Figure 4. The chlorides increase with time as did the corrosion shown in Figure 3. Chlorides, being held in close proximity to the steel by the soil and cement dusts, are probably the major source of corrosion. In this respect, flaking rust and scale on the webs and bottom flanges may be beneficial as the corrosive agents are removed with flaking and scaling of rust. Unfortunately, the new surfaces are quickly contaminated again by road spray, salts and dirt, and deposits are not removed from ledges and horizontal surfaces.

In a second series of tests, we compared the performance of Mayari R steel with plain carbon steel, locating panels beneath the Westbound Bridge as before and on the Armory Roof. There was little difference in the corrosion resistance of the steels on the bridge beams subjected to road salts and spray (Table 6), and both steels exhibited scaly rust. As expected, however, there was a significant difference in the corrosion behavior of the steels on the roof free from deposits (Table 7 and Figure 4). The corrosion of Mayari R steel decreases with time of exposure and exhibits a flattening of the corrosion-time curves, whereas plain carbon steel continues to corrode. Corrosion rates, based on the slopes of the 3- to 7-year portion of the corrosion-time curves, are as follows:

Location	Corrosion Rate, mils per year		Ratio Plain Carbon to Mayari R Steel
	Mayari R	Plain Carbon	
Vertical (web)	0.05	0.27	5.4
Horizontal (flange-bottom)	0.18	0.56	3.1
Horizontal (flange-top)	0.09	0.32	3.6
Average			4.0

Based on a comparison of 3- to 7-year slopes, the Mayari R steel shows an average of 4 times the corrosion resistance of plain carbon steel. Moreover, on the basis of the curvatures evident in Figure 5, we expect the superiority of Mayari R to increase further with time.

Thus, Mayari R is performing well everywhere except at the tunnel-like abutment condition where corrosion is variable but appears to have increased in amount at 8 years over that at 4 years. The reason for this increase may be due to a long-term increase in corrosion rate as a result of increasing accumulation of corrodants or to a short-term variation in rate due to variations in environmental conditions. Further testing is necessary to resolve this.

J. C. Zoccola

JCZ:djj

Attachments

TABLE 1.

COMPOSITION OF MAYARI R AND PLAIN CARBON STEELS
(Percent by Weight)

	C	Mn	P	S	Si	Cu	Ni	Cr
Mayari R (Test No. 1)	.09	.73	.077	.030	.24	.240	.75	.56
Mayari R (Test No. 2)	.09	.78	.080	.029	.36	.340	.72	.64
Plain Carbon (Test No. 2)	.13	.47	.011	.019	.05	.015	-	-

TABLE 2.

POSSIBLE SOURCES OF ROAD DIRT, SALTS AND SOIL

1. Truck ladings (bulk cement, slag, sand, limestone, gravel and evacuated soil).

2. Falloff from passenger cars and trucks.

3. Erosion of concrete highway by normal wear and from studded tires.

4. Windblown soil from turbulent movement of traffic and from natural conditions.

5. Winter deicing salts.

6. Conversion of lime dust by sulfur dioxide and carbon dioxide in the atmosphere and from traffic fumes to sulfates and carbonates.

TABLE 3.

ANALYSIS OF SOIL ON 4-YEAR CORROSION RACK

1. X-Ray Diffraction Analysis

Major Constituents		Minor Constituents	
gypsum	$CaSO_4\ 2H_2O$	Calcite	$CaCO_3$
silica	SiO_2	Calcium Chloride	$CaCl_2$
dolomite	$CaMg(CO_3)_2$	iron oxide	(αFeOOH)
salt	NaCl		

2. Chemical Analysis (Percent by Weight)

Aluminum	Sodium	Calcium	Chloride	Sulfate	Silica	Iron
2.2	4.9	12.4	6.7	11.8	28.2	3.0

3. Ion Microprobe Analysis (White Deposit Beneath Scale)-
Major amounts of sodium chloride and calcium carbonate

TABLE 4.

WEATHERING OF MAYARI R STEEL SPECIMENS ON THE NATIONAL GUARD ARMORY ROOF, DETROIT, MICHIGAN
(Test No. 1)

Note: All specimens were exposed on the Northland Towers roof for 1-1/2 years before removal to the armory roof for remainder of exposure.

Position	Weathering Loss, mils				
	0.50 Year	1.00 Year	2.00 Years	4.00 Years	8.17 Years
Vertical (Web)	0.46	0.72	1.18	1.36	2.16
	0.49	0.77	1.22	1.64	1.82
	0.53	0.83	1.43	1.72	1.87
	0.61	0.85	1.50	*	*
Average	0.52	0.76	1.33	1.57	1.95
Horizontal (Flange-Bottom)	0.66	1.11	1.84	1.88	2.52
	0.67	1.12	2.02	1.92	2.93
	0.79	1.23	2.12	2.52	2.49
	0.90	1.26	2.22	*	*
Average	0.76	1.18	2.05	2.11	2.65
Horizontal (Flange-Top)	0.56	1.02	1.55	1.64	1.92
	0.71	1.03	1.59	1.76	2.44
	0.69	1.13	1.65	2.16	2.51
	1.01	1.22	1.94	*	*
Average	0.74	1.10	1.68	1.85	2.29
Overall Average	0.67	1.01	1.69	1.84	2.30

* In each case, one specimen was retained to show the surface appearance.

TABLE 5.

WEATHERING OF MAYARI R STEEL SPECIMENS BENEATH THE WESTBOUND SERVICE BRIDGE, DETROIT, MICHIGAN
(Test No. 1)

Position	Weathering Loss, mils 0.50 Year	1.00 Year	2.00 Years	3.90 Years	8.04 Years
Vertical (Web)	0.48	0.81	1.54	2.49	10.07
	0.48	0.85	1.68	3.00	6.61
	0.50	0.86	1.78	3.51	10.64
	0.51	0.89	1.81	*	*
Average	0.49	0.85	1.70	3.00	9.11
Horizontal (Flange-Bottom)	0.51	0.81	1.44	3.35	7.28
	0.52	0.84	1.58	3.43	11.12
	0.53	0.86	1.62	4.33	8.73
	0.54	0.89	1.77	*	*
Average	0.53	0.85	1.60	3.70	9.04
Horizontal (Flange-Top)	0.36	0.73	1.70	4.05	11.85
	0.37	0.75	1.85	4.41	10.62
	0.43	0.75	2.20	4.84	11.95
	0.45	0.83	2.73	*	*
Average	0.40	0.77	2.12	4.43	11.47
Overall Average	0.47	0.82	1.81	3.71	9.87

* In each case, one specimen was retained to show the surface appearance.

TABLE 6.

WEATHERING OF MAYARI R AND PLAIN CARBON STEELS BENEATH THE WESTBOUND SERVICE BRIDGE, DETROIT, MICHIGAN
(Test No. 2)

Position		Weathering Loss, mils		
	Mayari R Steel		Plain Carbon Steel	
	2.92 Years	7.00 Years	2.92 Years	7.00 Years
Vertical (Web)	2.04	4.58	3.01	6.89
	2.04	7.08	3.01	8.82
Average	2.04	5.83	3.01	7.86
Horizontal (Flange-Bottom)	2.19	7.73	3.56	8.82
	2.72	8.78	4.03	9.28
Average	2.41	8.26	3.80	9.05
Horizontal (Flange-Top)	2.51	9.62	3.91	9.77
	2.72	9.49	4.06	7.63
Average	2.62	9.56	3.99	8.70
Overall Average	2.35	7.88	3.60	8.53

TABLE 7.

WEATHERING OF MAYARI R AND PLAIN CARBON STEELS ON THE NATIONAL GUARD ARMORY ROOF, DETROIT, MICHIGAN (Test No. 2)

	Weathering Loss, mils			
	Mayari R Steel		Plain Carbon Steel	
Position	2.97 Years	7.11 Years	2.97 Years	7.11 Years
Vertical (Web)	1.42	1.67	1.90	2.61
	1.42	1.54	1.96	3.49
Average	1.42	1.61	1.93	3.05
Horizontal (Flange-Bottom)	1.99	2.82	2.52	6.45
	2.02	2.69	3.36	4.03
Average	2.01	2.76	2.94	5.24
Horizontal (Flange-Top)	1.49	2.15	2.35	4.10
	1.90	2.01	2.73	3.65
Average	1.70	2.08	2.54	3.88
Overall Average	1.71	2.15	2.47	4.06

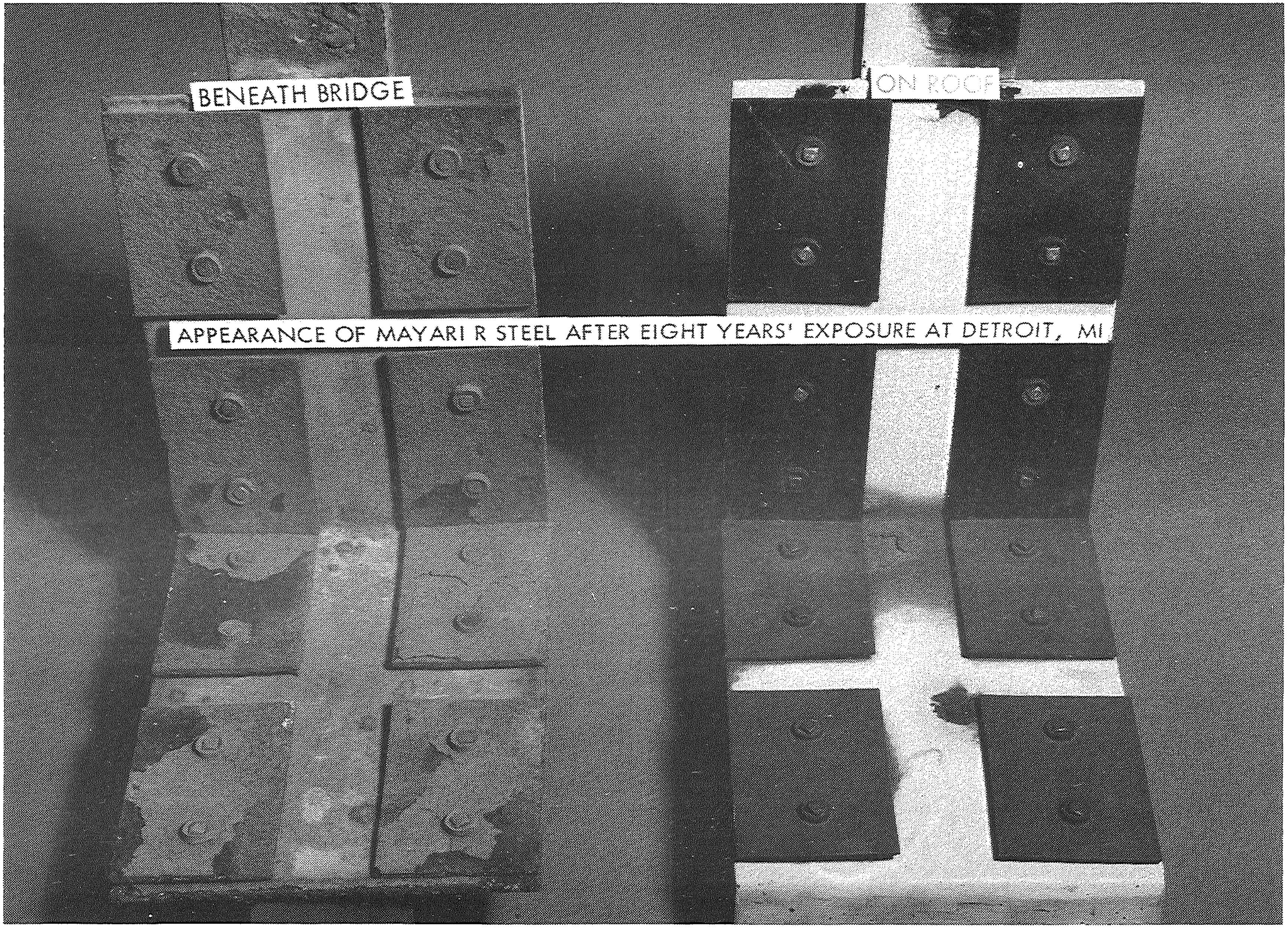

Figure 1. Test No. 1.

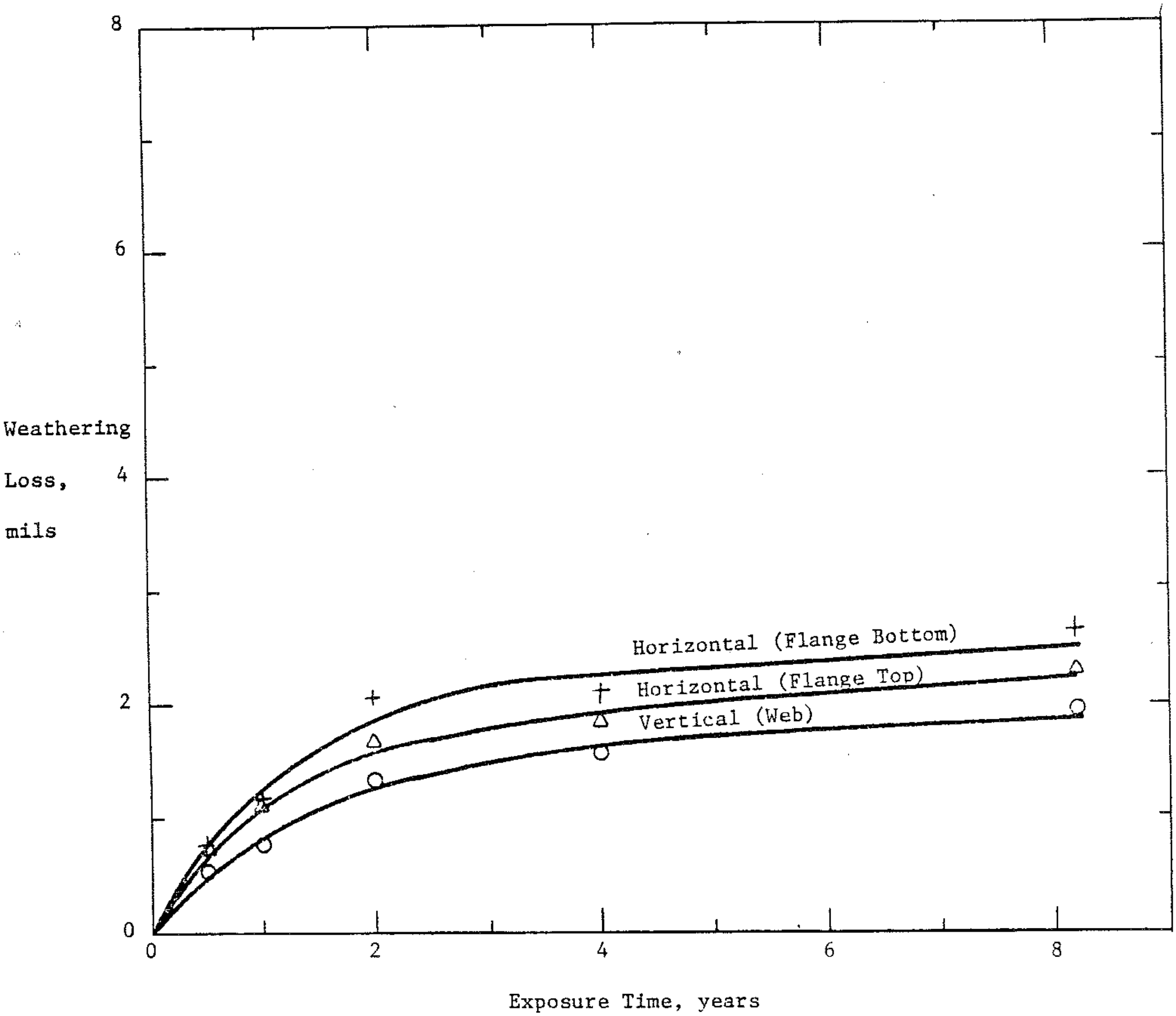

FIGURE 2. WEATHERING-TIME CURVES OF MAYARI R STEEL SPECIMENS ON THE BUILDING ROOF IN DETROIT, MI (Test No. 1)

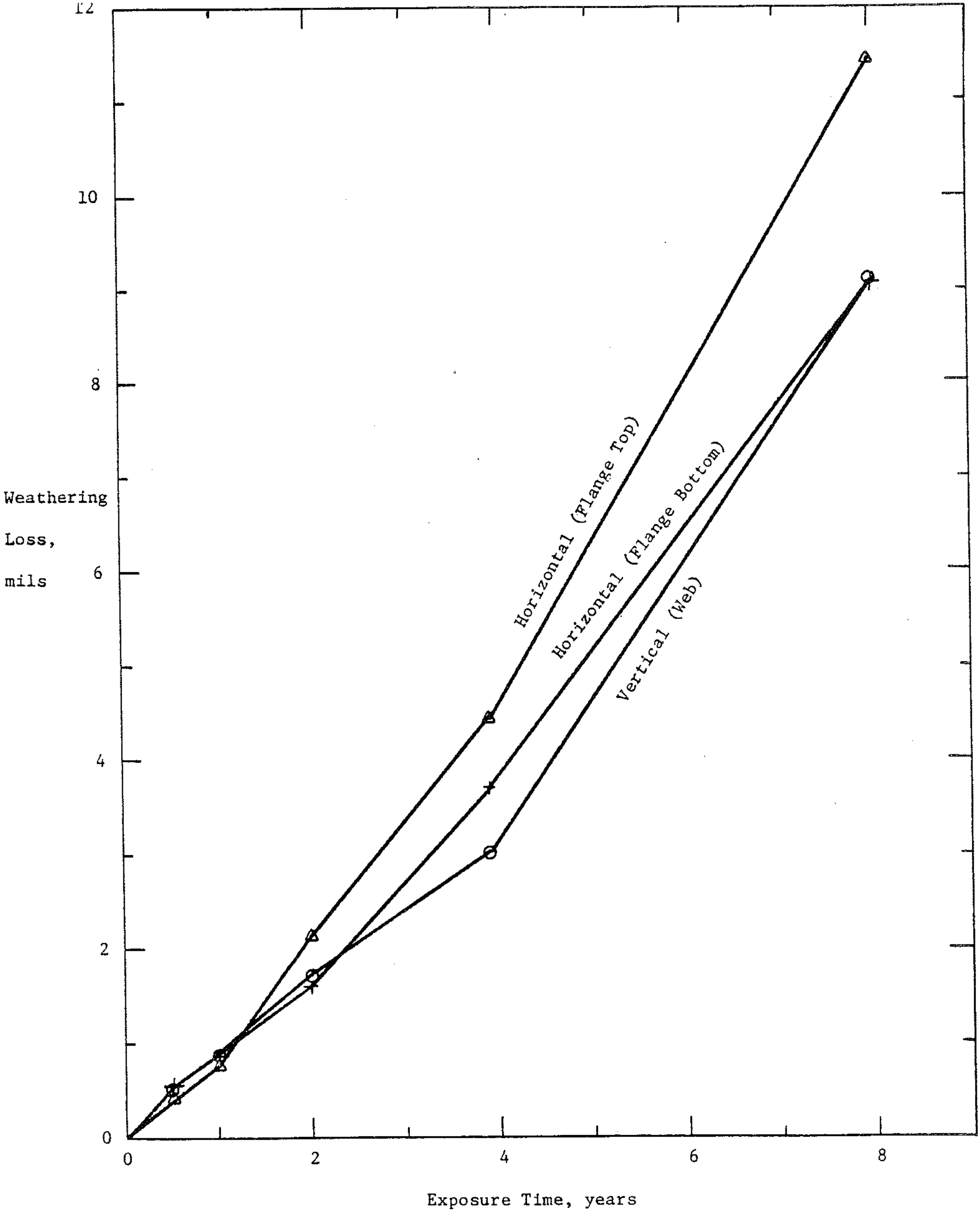

FIGURE 3. WEATHERING-TIME CURVES OF MAYARI R STEEL SPECIMENS BENEATH THE WESTBOUND SERVICE BRIDGE, DETROIT, MI (Test No. 1)

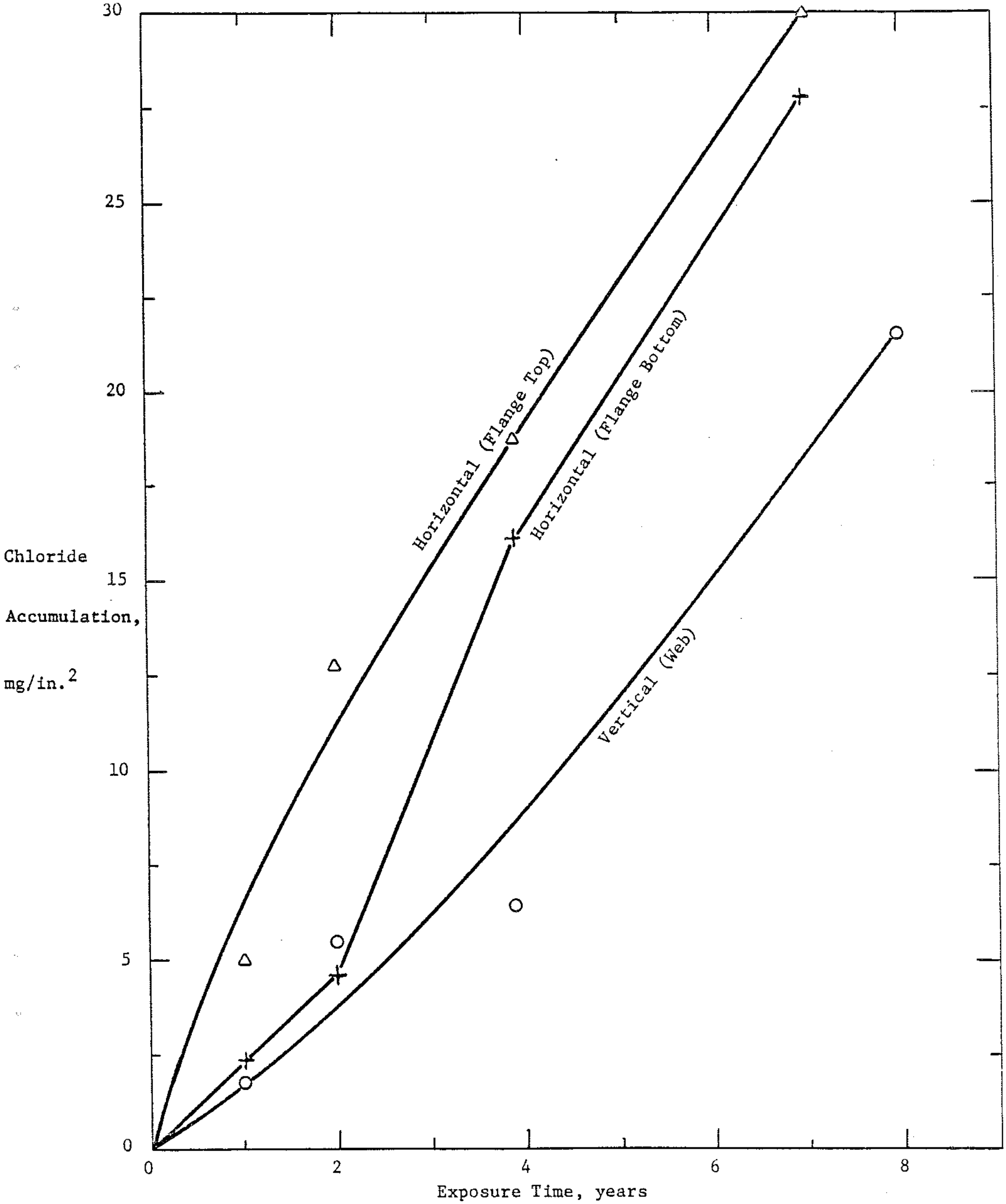

FIGURE 4. CHLORIDE ACCUMULATION ON STEEL PANELS BENEATH THE WESTBOUND SERVICE BRIDGE, DETROIT, MI (Test No. 1)

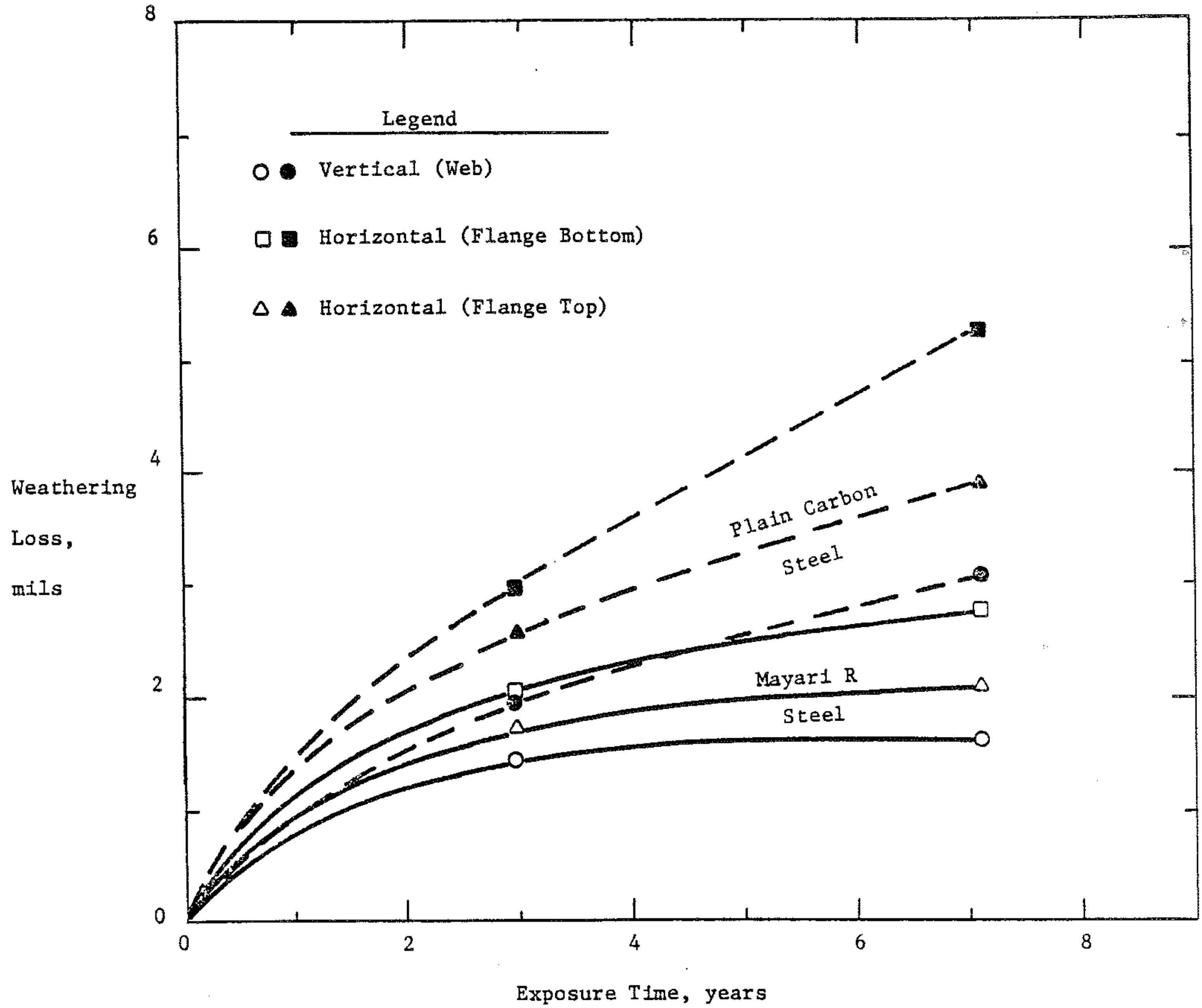

FIGURE 5. WEATHERING-TIME CURVES OF MAYARI R AND PLAIN CARBON STEEL SPECIMENS ON THE BUILDING ROOF IN DETROIT, MI
(Test No. 2)

APPENDIX B

Meeting
with Bethlehem Steel on Cooperative
ASTM A242 Steel Tests on 8 Mile Road Bridge
April 13, 1976

Bethlehem Personnel	Department Personnel	
R. Wakefield	K. A. Allemeier	L. T. Oehler
D. Frederickson	W. J. MacCreery	A. J. Permoda
J. Embree	G. J. Hill	A. J. Bryhan

The meeting was held in K. A. Allemeier's office.

R. Wakefield distributed the 8-year report on subject tests with an April 12, 1976 letter of transmittal to K. A. Allemeier. The report showed that the corrosion rate on the panels at the bridge was still linear over the last 4-year period, without decreasing as is normal. The exposure conditions were abnormal which can be verified visually from the high accumulation of dirt on the bridge girders in the test area, a localized peculiarity. G. Hill mentioned that the high corrosion rate noted at the bridge test site was also present under leaky joints at several other unpainted steel structures, including I-75 over Fort Street. Other findings in the report were also discussed.

Bethlehem Steel representatives would like to extend the field tests for another 8-year period with a second group of test specimens, exposed at the same two sites, plus an additional set over NB Lodge Freeway, considered a normal road site. They also would like to include some steel specimens protected by paint.

It was decided that R. Wakefield would submit such a request for Department consideration. This would include some of their detailed suggestions.

Comment was made about the Research Laboratory's up-coming survey of bridge conditions. Approximately 12-15 bridges will be evaluated in the field for structural problems of corrosion and welds. G. Hill requested we compare weathering of bridges that were blast cleaned with those that were not. The preliminary results would be available by mid-summer.

APPENDIX C

STATE OF MICHIGAN

JAMES J. BLANCHARD, GOVERNOR

DEPARTMENT OF TRANSPORTATION

MATERIALS AND TECHNOLOGY DIVISION
SECONDARY GOVERNMENTAL COMPLEX
POST OFFICE BOX 30049, LANSING, MICHIGAN 48909
PHONE: (517) 322-1085

JAMES P. PITZ, DIRECTOR

November 6, 1985

Director of Research
Bethlehem Steel Corporation
Bethlehem, Pennsylvania 18016

Dear Sir:

In 1977 the Michigan Department of Transportation and the Bethlehem Steel Corporation started a 16 year corrosion rate study of various steels. The test site for this study is the Detroit area on the 8 Mile Road over US-10 bridge. In the past we have been working with Jim Zoccola of your Research Department. It is our understanding that Jim has retired, therefore, we need a new contact person.

In 1983 we set-up a rust removal system using Clark's Solution. Prior to that we could not remove rust, therefore, all panels were tested at your facilities. We are aware of your cutbacks in research staff and funds, therefore, are willing to do the necessary lab work on the 8 year panels which were removed November 6, 1985. In order to do this we will need the original weights of the test coupons.

To date, we have not received any of the data pertaining to the 2 and 4 year panels removed in 1979 and 1981 and processed by J. Zoccola. Please provide this data also, so we will have a complete data set.

Since this test was undertaken to determine the validity of the first 8 year study at the same location and the panels will change even in the lab, the Department is anxious to start the lab procedures as soon as possible. Your prompt response to this request would be most appreciated.

Sincerely,

MATERIALS & TECHNOLOGY DIVISION

Martin L. O'Toole

Martin L. O'Toole
Asst. Engineer of Materials & Technology

MLO:GLT:cgc

cc: L. T. Oehler
G. L. Tinklenberg

APPENDIX D

Bethlehem Steel Corporation

BETHLEHEM, PA 18016

M. J. ROBERTS
DIRECTOR OF RESEARCH

November 15, 1985

R507-E-B476
1800-1e

Dr. Gary L. Tinklenberg
Michigan Department of Transportation
Materials and Technology Division
P. O. Box 30049
Lansing, MI 48909

Reference: Letter from Martin L. O'Toole, November 6, 1985.

Dear Gary:

I enjoyed talking with you and Mr. O'Toole on November 14 in relation to your request for information on the weathering-steel corrosion tests being conducted in Detroit. As outlined in the reference letter, I understand you want 2- and 4-year weight losses, and initial weights for the 8- and 16-year removals.

Enclosed are copies from J. C. Zaccola's notebook which contains the information you requested. I thought it best to transmit it in this form, even though handwritten, rather than risk transcribing errors. Please call me at (215) 694-6674 if you have any questions.

Given the current manpower situation at Bethlehem, we agree that it makes sense for you to proceed with cleaning and weighing of the 8-year removals at your laboratories. I'll be very interested in your results. In the meantime, I will attempt to find out more about the cleaning procedure and paint system employed for the painted-panel tests.

Sincerely,

Herb Townsend

H. E. Townsend
Senior Research Fellow
Product Research

HET:gfc

Enclosure

cc: Mr. Martin L. O'Toole

NOTE: The copies of Mr. Zaccola's notebooks are on file at the Materials and Technology Division, but would not reproduce well enough to be included here.

APPENDIX E

TEST PROGRAM BACKGROUND

These tests were set up to show that the high corrosion rates experienced on the previous eight-year tests on the same structure were due to the placement of the panels, e.g., next to a high vertical wall. Therefore, in addition to the same two exposures from the previous test a set was exposed on the center of the structure far from the vertical walls.

Three duplicate sets of various steel panels were placed horizontally, two on the structure and the other on a roof about a half-mile away. There were six different steels in each set and eight panels of each steel type. After two, four, eight and sixteen years two of each type were to be removed and corrosion rates determined. (There was also an incomplete set of experimental steel, why it was incomplete is not known.)

The three environments are:

R - Roof of the Detroit Armory - The Armory is a large four-storey building about one-half mile from the bridge exposure site. It is located on a major urban thoroughfare surrounded by a large shopping mall and mostly residential areas. There is some industry (particularly to the east) and the Armory has a large heating plant.

S - Over the southbound lanes of US 10 on a structure with 14-1/2 ft of clearance, about 12 to 14 ft from a vertical wall, one set was attached on the webs facing oncoming traffic.

N - Over the northbound traffic in approximately the center of the structure with a clearance of 16 ft. This new site was considered to be free from the effects of the vertical side walls. The panels were also attached to the web facing oncoming traffic.

The seven steel types are:

912 - A242, Type I
916 - Cu-bearing
919 - Plain carbon
921 - A588
914 - Low nickel A588
915 - Experimental (C-guard)
917 - Experimental (low sulpher, Al-bearing)

Chemical information is listed in Table 1.

All three sets of panels were exposed on the roof of the Armory on December 17, 1976. On June 29, 1977 the sets scheduled for bridge exposure were placed on the structure. This was done to better duplicate

TABLE 1
STEELS COMPOSITION

CODE	C	Mn	P	S	Si	Ni	Cr	Cu	Al	V	Mo
912	0.09	0.65	0.11	0.032	0.29	0.66	0.52	0.27			0.01
916	0.042	0.36	0.006	0.024	0.01	0.01	0.01	0.26	0.005	0.002	0.02
919	0.18	0.73	0.007	0.017	0.01	0.01	0.02	0.015	0.005	0.002	0.02
921	0.14	1.07	0.011	0.022	0.28	0.32	0.55	0.28	0.026	0.023	0.02
914	0.15	0.85	0.013	0.034	0.24	0.14	0.50	0.29	0.063	0.025	0.02
915	0.13	0.79	0.13	0.009	0.07	0.56	0.01	0.54	0.005	0.002	0.02
917	0.11	0.77	0.085	0.006	0.34	0.04	0.51	0.12	0.49	0.002	0.02

TABLE 2
COMPARISON OF A242 IN FIRST AND SECOND STUDY

CODE	C	Mn	P	S	Si	Ni	Cr	Cu	Mo
None	0.09	0.78	0.08	0.029	0.36	0.72	0.64	0.34	N
912	0.09	0.65	0.11	0.032	0.29	0.66	0.52	0.27	0.01

a typical exposure during a bridge construction, i.e., a mild exposure prior to the normal highway environment. However, since all the panels were blasted to remove mill scale and this scale was normally left on the structure at that time, the panels were atypical.

The results are as follows:

CODE EXPLANATIONS

WTO	Original weight
WTE	Weight after exposure
TLG	Total weight loss in grams
TLM	Total loss in mils, calculated from TLG
YAML	Yearly average mil loss, calculated by dividing the TLM by the exposure time
SITE	Yearly average mill loss from time of exposure in different environments, e.g., the loss on the roof for the first six months is subtracted from the original weight and this is used as the starting point
ILG	Interval loss in grams, calculates an exposure weight loss in the preceding time interval. It determines a starting point by calculating an interval starting weight from the previous data.
IR	Interval rate, ILG converted to mils per year. The interval rate is the average slope of the corrosion curve during the time interval. (The interval rate for the 0-2 interval would be the same as the first SITE value.)

	WTO	WTE	TLG	TLM	YAML	SITE	ILG	IR
912 3 R	320.7746	313.5195	7.2551	1.1460	0.4424	0.4450	0.0000	0.0000
912 4 R	320.7433	313.5455	7.1978	1.1370	0.4424	0.4450	0.0000	0.0000
912 1 R	314.6684	305.7770	8.8914	1.4045	0.2868	0.2674	1.5531	0.1113
912 2 R	318.8086	310.3220	8.4866	1.3405	0.2868	0.2674	1.5531	0.1113
912 5 R	321.2420	311.0600	10.1820	1.6601	0.1897	0.1742	1.5856	0.0623
912 6 R	322.4818	311.8300	10.6518	1.7224	0.1897	0.1742	1.5856	0.0623
912 7 R	320.7992							
912 8 R	320.5740							
912 11 S	319.3641	303.7435	15.6206	2.4674	1.0249	1.1831	0.0000	0.0000
912 12 S	319.2232	301.3651	17.8581	2.8208	1.0249	1.1831	0.0000	0.0000
912 9 S	320.9183	290.4900	30.4283	4.8064	1.0815	1.1618	15.9514	1.1427
912 10 S	320.4156	285.3180	35.0976	5.5440	1.0815	1.1618	15.9514	1.1427
912 13 S	319.7686	268.2700	51.4986	8.3952	0.9540	0.9897	19.4770	0.7699
912 14 S	318.7247	266.0300	52.6947	8.6154	0.9540	0.9897	19.4770	0.7699
912 15 S	322.5701							
912 16 S	319.7657							
912 19 N	318.5156	308.3115	10.2041	1.6118	0.6323	0.6857	0.0000	0.0000
912 20 N	319.8451	309.3927	10.4524	1.6510	0.6323	0.6857	0.0000	0.0000
912 17 N	320.5603	303.0700	17.4903	2.7627	0.5740	0.5906	7.0122	0.5023
912 18 N	320.7956	303.5086	17.2870	2.7306	0.5740	0.5906	7.0122	0.5023
912 21 N	321.6857	297.6000	24.0857	3.9415	0.4445	0.4460	6.9036	0.2731
912 22 N	318.3259	293.9000	24.4259	3.9832	0.4445	0.4460	6.9036	0.2731
912 23 N	314.8111							
912 24 N	321.5712							
916 3 R	579.0193	565.5425	13.4768	2.0537	0.7987	0.8034	0.0000	0.0000
916 4 R	572.9275	559.3590	13.5685	2.0676	0.7987	0.8034	0.0000	0.0000
916 1 R	580.5643	563.5220	17.0423	2.5970	0.5439	0.5122	3.5138	0.2428
916 2 R	574.9793	557.8630	17.1163	2.6083	0.5439	0.5122	3.5138	0.2428
916 5 R	580.5595	561.5500	19.0095	3.0870	0.3532	0.3259	2.2075	0.0870
916 6 R	578.6744	559.0000	19.6744	3.2100	0.3532	0.3259	2.2075	0.0870
916 7 R	576.8305							
916 8 R	571.1767							
916 11 S	573.8746	549.2890	24.5856	3.7465	1.4771	1.6631	0.0000	0.0000
916 12 S	575.9074	550.4750	25.4324	3.8755	1.4771	1.6631	0.0000	0.0000
916 9 S	583.2406	544.4515	38.7891	5.9109	1.2103	1.2621	12.7469	0.8809
916 10 S	577.9920	540.7725	37.2195	5.6717	1.2103	1.2621	12.7469	0.8809
916 13 S	578.7297	516.1000	62.6297	10.1927	1.1894	1.2181	27.0913	1.0746
916 14 S	570.7144	503.9300	66.7844	11.0137	1.1894	1.2181	27.0913	1.0746
916 15 S	570.7314							
916 16 S	576.3652							
916 19 N	576.2922	561.9420	14.3502	2.1868	0.8533	0.8726	0.0000	0.0000
916 20 N	578.9330	564.3890	14.5440	2.2163	0.8533	0.8726	0.0000	0.0000
916 17 N	571.5627	547.0598	24.5029	3.7339	0.7888	0.7877	10.3936	0.7183
916 18 N	577.8195	552.7875	25.0320	3.8145	0.7888	0.7877	10.3936	0.7183
916 21 N	572.2854	535.2300	37.0554	6.0498	0.6965	0.6922	13.3587	0.5296
916 22 N	567.6066	528.8200	38.7866	6.3681	0.6965	0.6922	13.3587	0.5296
916 23 N	571.2902							
916 24 N	571.5817							
919 3 R	336.9566	320.4025	16.5541	2.6149	0.9721	0.9778	0.0000	0.0000
919 4 R	336.4355	321.2350	15.2005	2.4010	0.9721	0.9778	0.0000	0.0000
919 1 R	337.0945	318.2400	18.8545	2.9782	0.6333	0.5911	3.2887	0.2356
919 2 R	337.1513	317.6345	19.5168	3.0828	0.6333	0.5911	3.2887	0.2356
919 5 R	336.3068	314.1600	22.1468	3.6109	0.4039	0.3690	2.9709	0.1169
919 6 R	338.0846	315.9100	22.1746	3.5899	0.4039	0.3690	2.9709	0.1169
919 7 R	337.0602							
919 8 R	338.4979							
919 11 S	336.0367	309.3051	26.7316	4.2225	1.7146	1.9187	0.0000	0.0000
919 12 S	333.9738	304.6945	29.2793	4.6249	1.7146	1.9187	0.0000	0.0000
919 9 S	338.0458	299.1550	38.8908	6.1431	1.3502	1.3979	12.7381	0.9125
919 10 S	335.6564	292.7430	42.9134	6.7785	1.3502	1.3979	12.7381	0.9125
919 13 S	339.2311	253.5600	85.6711	13.8892	1.4226	1.4559	37.0631	1.4573
919 14 S	336.7515	266.2000	70.5515	11.4762	1.4226	1.4559	37.0631	1.4573
919 15 S	339.0330							
919 16 S	338.3739							
919 19 N	334.9637	318.5960	16.3677	2.5854	1.0266	1.0469	0.0000	0.0000
919 20 N	338.6441	321.4760	17.1681	2.7118	1.0266	1.0469	0.0000	0.0000
919 17 N	336.3702	310.0875	26.2827	4.1516	0.8724	0.8602	9.6959	0.6946
919 18 N	335.8725	309.2990	26.5735	4.1975	0.8724	0.8602	9.6959	0.6946
919 21 N	335.5947	296.0000	39.5947	6.4139	0.7344	0.7217	13.8047	0.5438
919 22 N	336.8902	296.0000	40.8902	6.6809	0.7344	0.7217	13.8047	0.5438
919 23 N	339.4111							
919 24 N	339.7222							

	WTO	WTE	TLG	TLM	YAML	SITE	ILG	IR
921 3 R	420.3315	409.9987	10.3328	1.6125	0.6238	0.6275	0.0000	0.0000
921 4 R	372.5413	362.2470	10.2943	1.6065	0.6238	0.6275	0.0000	0.0000
921 1 R	413.0041	401.1295	11.8746	1.8531	0.3937	0.3650	2.2705	0.1607
921 2 R	337.9192	325.6480	12.2712	1.9150	0.3937	0.3650	2.2705	0.1607
921 5 R	378.3873	364.2800	14.1073	2.2982	0.2574	0.2349	1.9294	0.0762
921 6 R	367.9934	353.9600	14.0334	2.2908	0.2574	0.2349	1.9294	0.0762
921 7 R	346.6786							
921 8 R	396.7580							
921 11 S	418.9456	398.5638	20.3818	3.1807	1.1780	1.3297	0.0000	0.0000
921 12 S	331.3326	312.7643	18.5683	2.8977	1.1780	1.3297	0.0000	0.0000
921 9 S	372.5899	337.9690	34.6209	5.4028	1.0593	1.1140	13.9278	0.9857
921 10 S	336.2663	305.9260	30.3403	4.7348	1.0593	1.1140	13.9278	0.9857
921 13 S	336.3442	283.4000	52.9442	8.6736	0.9958	1.0227	20.2699	0.8001
921 14 S	410.4852	354.5000	55.9852	9.0811	0.9958	1.0227	20.2699	0.8001
921 15 S	331.6161							
921 16 S	396.9396							
921 19 N	334.2720	322.5864	11.6856	1.8236	0.7297	0.7617	0.0000	0.0000
921 20 N	333.8593	321.4175	12.4418	1.9416	0.7297	0.7617	0.0000	0.0000
921 17 N	381.1637	362.2090	18.9547	2.9580	0.6073	0.6054	5.5563	0.3932
921 18 N	342.3659	324.0795	18.2864	2.8537	0.6073	0.6054	5.5563	0.3932
921 21 N	343.0272	313.9800	29.0472	4.6807	0.5185	0.5135	10.1638	0.3995
921 22 N	367.1545	339.2500	27.9045	4.5646	0.5185	0.5135	10.1638	0.3995
921 23 N	404.8360							
921 24 N	366.4535							
914 3 R	384.4345	374.3760	10.0585	1.5634	0.6192	0.6229	0.0000	0.0000
914 4 R	429.7320	419.2331	10.4989	1.6319	0.6192	0.6229	0.0000	0.0000
914 1 R	385.1616	371.8830	13.2786	2.0639	0.4229	0.3984	3.6947	0.2604
914 2 R	351.9878	339.2288	12.7590	1.9832	0.4229	0.3984	3.6947	0.2604
914 5 R	349.9452	334.0800	15.8652	2.5863	0.2991	0.2797	3.9983	0.1578
914 6 R	348.9766	332.1300	16.8466	2.7470	0.2991	0.2797	3.9983	0.1578
914 7 R	354.7833							
914 8 R	360.3977							
914 11 S	366.3195	347.0930	19.2265	2.9884	1.1980	1.3563	0.0000	0.0000
914 12 S	429.5218	408.9763	20.5455	3.1934	1.1980	1.3563	0.0000	0.0000
914 9 S	430.0433	392.4175	37.6258	5.8483	1.2774	1.3600	19.5524	1.3783
914 10 S	358.3429	317.3188	41.0241	6.3765	1.2774	1.3600	19.5524	1.3783
914 13 S	431.2881	368.5200	62.7681	10.3098	1.1856	1.2255	20.7067	0.8220
914 14 S	435.5005	369.3200	66.1805	10.8293	1.1856	1.2255	20.7067	0.8220
914 15 S	352.9941							
914 16 S	433.2911							
914 19 N	432.6381	420.9065	11.7316	1.8235	0.7042	0.7306	0.0000	0.0000
914 20 N	430.4216	418.7740	11.6476	1.8104	0.7042	0.7306	0.0000	0.0000
914 17 N	428.8205	407.2305	21.5900	3.3558	0.7027	0.7133	9.9828	0.7037
914 18 N	431.3453	409.6690	21.6763	3.3692	0.7027	0.7133	9.9828	0.7037
914 21 N	381.6869	351.3200	30.3669	4.9429	0.5629	0.5611	10.4588	0.4123
914 22 N	427.9768	396.7000	31.2768	5.0936	0.5629	0.5611	10.4588	0.4123
914 23 N	348.5918							
914 24 N	432.7789							
915 3 R	378.7258	371.2215	7.5043	1.1664	0.4512	0.4539	0.0000	0.0000
915 4 R	371.1285	363.6535	7.4750	1.1619	0.4512	0.4539	0.0000	0.0000
915 1 R	362.7181	352.6898	10.0283	1.5587	0.3096	0.2919	2.1133	0.1490
915 2 R	379.8040	370.7716	9.0324	1.4039	0.3096	0.2919	2.1133	0.1490
915 5 R	355.9956	345.0700	10.9256	1.7987	0.2059	0.1909	1.9934	0.0788
915 6 R	362.9487	351.4000	11.5487	1.8718	0.2059	0.1909	1.9934	0.0788
915 7 R	368.4152							
915 8 R	347.4700							
915 11 S	360.9725	342.8674	18.1051	2.8141	1.0761	1.2457	0.0000	0.0000
915 12 S	376.0194	358.4015	17.6179	2.7384	1.0761	1.2457	0.0000	0.0000
915 9 S	349.2687	317.6165	31.6522	4.9198	1.1072	1.1895	16.5372	1.1657
915 10 S	374.2955	337.7768	36.5187	5.6762	1.1072	1.1895	16.5372	1.1657
915 13 S	355.9380	299.2000	56.7380	9.2905	1.0899	1.1341	24.7703	0.9800
915 14 S	381.6458	319.4400	62.2058	10.1424	1.0899	1.1341	24.7703	0.9800
915 15 S	350.1832							
915 16 S	364.8452							
915 19 N	356.6515	346.6352	10.0163	1.5569	0.6262	0.6757	0.0000	0.0000
915 20 N	375.8634	365.0900	10.7734	1.6745	0.6262	0.6757	0.0000	0.0000
915 17 N	361.6545	342.6378	19.0167	2.9558	0.6112	0.6314	8.5505	0.6027
915 18 N	361.9445	343.3290	18.6155	2.8934	0.6112	0.6314	8.5505	0.6027
915 21 N	379.5600	349.8900	29.6700	4.8562	0.5382	0.5454	9.9531	0.3961
915 22 N	360.3783	331.6600	28.7183	4.7390	0.5382	0.5454	9.9531	0.3961
915 23 N	359.4796							
915 24 N	378.4917							

APPENDIX F

Bethlehem Steel Corporation

BETHLEHEM, PA 18016

D. J. BLICKWEDE
VICE PRESIDENT AND
DIRECTOR OF RESEARCH
T. B. WINKLER
ASSISTANT VICE PRESIDENT, RESEARCH

BETHLEHEM STEEL

J. W. FRAME
MANAGER
PRODUCT RESEARCH
E. H. MAYER
ASSISTANT MANAGER

December 16, 1976

Dr. A. J. Permoda
Supervising Engineer
Materials Research Unit
Research Laboratory Section
735 E. Saginaw Street
Lansing, MI 48906

Dear Dr. Permoda:

In regard to our corrosion test of weathering steels at the Eight Mile Interchange near Detroit, we are forwarding you by Roadway Express (closed van), 7 wooden crates containing our corrosion test racks, holders and specimens. Table 1 shows the box number and contents of the boxes, as well as the rack code numbers (identified with an aluminum tag and weld bead on the side of the rack), year of removal and location of the racks. There are a total of 45 racks, 10 rack holders and 168 panels.

Figures 1 to 4 illustrate the racks and panels (with location of each rack) that will be removed after 2, 4, 8 and 16 years on the Westbound Service Bridge above the southbound (SB) and northbound (NB) lanes of the expressway and on the Armory Roof (AR).

As agreed in our telephone conversations, you plan to initially expose all of the materials on the Armory Roof, and in the Spring, transfer the bridge racks to the proper location on the bridge, i.e., on steel girders near the shoulder of the road over the SB lanes and near the exit ramp of the highway over the NB lanes. In this manner, the specimen will be allowed to form some oxide before exposure to winter deicing salts and other deposits as well as permit safe installation of the rack holders and racks. Each holder will contain 3 racks and will be installed on separate bridge beams, excluding the fascia beam. Table 2 shows the composition of the steels.

We are aware of your retirement plans and wish you the best of luck should we be unable to see you before then. Please let us know who will follow this test during your absence. In the Spring, we will write a letter to your successor, requesting the designated racks and rack holders be transferred and installed in random fashion on the bridge beams. We would like to be present during this time to take photographs of the racks at the various locations and to inspect the bridge girders.

Should you have any questions, please call me at (215) 694-6936. We want to wish you a pleasant Christmas holiday and, again, wish you luck on your retirement.

Very truly yours,

Jim Zoccola

J. C. Zoccola
Engineer
Corrosion Mechanisms

JCZ:djj

Attachments

TABLE 1. CODE NUMBER AND LOCATION OF TEST RACKS ON THE WESTBOUND SERVICE BRIDGE AND ARMORY ROOF, DETROIT, MI

Box Code Number	Number of Racks	Rack Code Numbers*	Removal (years)	Location**
1	6	1,13,25	2	Bridge-Southbound
		2,14,26	4	Bridge-Southbound
2	6	3,15,27	8	Bridge-Southbound
		4,16,28	16	Bridge-Southbound
3	6	37	4	Bridge-Southbound
		38	8	Bridge-Southbound
		39	16	Bridge-Southbound
		5,17,29	2	Bridge-Northbound
4	6	6,18,30	4	Bridge-Northbound
		7,19,31	8	Bridge-Northbound
5	6	8,20,32	16	Bridge-Northbound
		40	4	Bridge-Northbound
		41	8	Bridge-Northbound
		42	16	Bridge-Northbound
6	15	9,21,33	2	Armory Roof
		10,22,34,43	4	Armory Roof
		11,23,35,44	8	Armory Roof
		12,24,36,45	16	Armory Roof
7	10 rack holders			Bridge-Southbound Bridge-Northbound

* Rack code numbers are welded on the side of the racks and further identified by an aluminum tag. The racks and holders are constructed of Mayari R weathering steel.

** The racks are to be located on the Westbound Service Bridge over the southbound or northbound concrete lanes of the James Couzens Expressway.

TABLE 2. CODE NUMBER AND COMPOSITION OF STEELS IN SECOND SERIES OF TESTS AT DETROIT, MI

Code	Steel	Composition, % by Weight									
		C	Mn	P	S	Si	Ni	Cr	Cu	Al	V
912	Mayari R	.090	.65	.110	.032	.29	.66	.52	.27	–	–
918	Mayari R (painted)	.090	.73	.077	.030	.24	.75	.56	.24	–	–
921	Mayari R-50	.140	1.07	.011	.022	.28	.32	.55	.28	.026	.023
914	Low-Ni, Mayari R-50 (experimental)	.150	.85	.013	.034	.24	.14	.50	.29	.063	<.02
915	"C-Guard"	.130	.79	.130	.009	.07	.56	.01	.54	<.005	<.002
916	Cu-Bearing	.042	.36	.006	.024	<.01	.01	.01	.26	<.005	<.002
919	Plain Carbon	.180	.73	.007	.017	<.01	<.01	.02	.015	<.005	<.002
917	Low-S, Al-Bearing Alloy (experimental)	.084	.77	.098	.006	.35	.04	.55	.11	.540	–

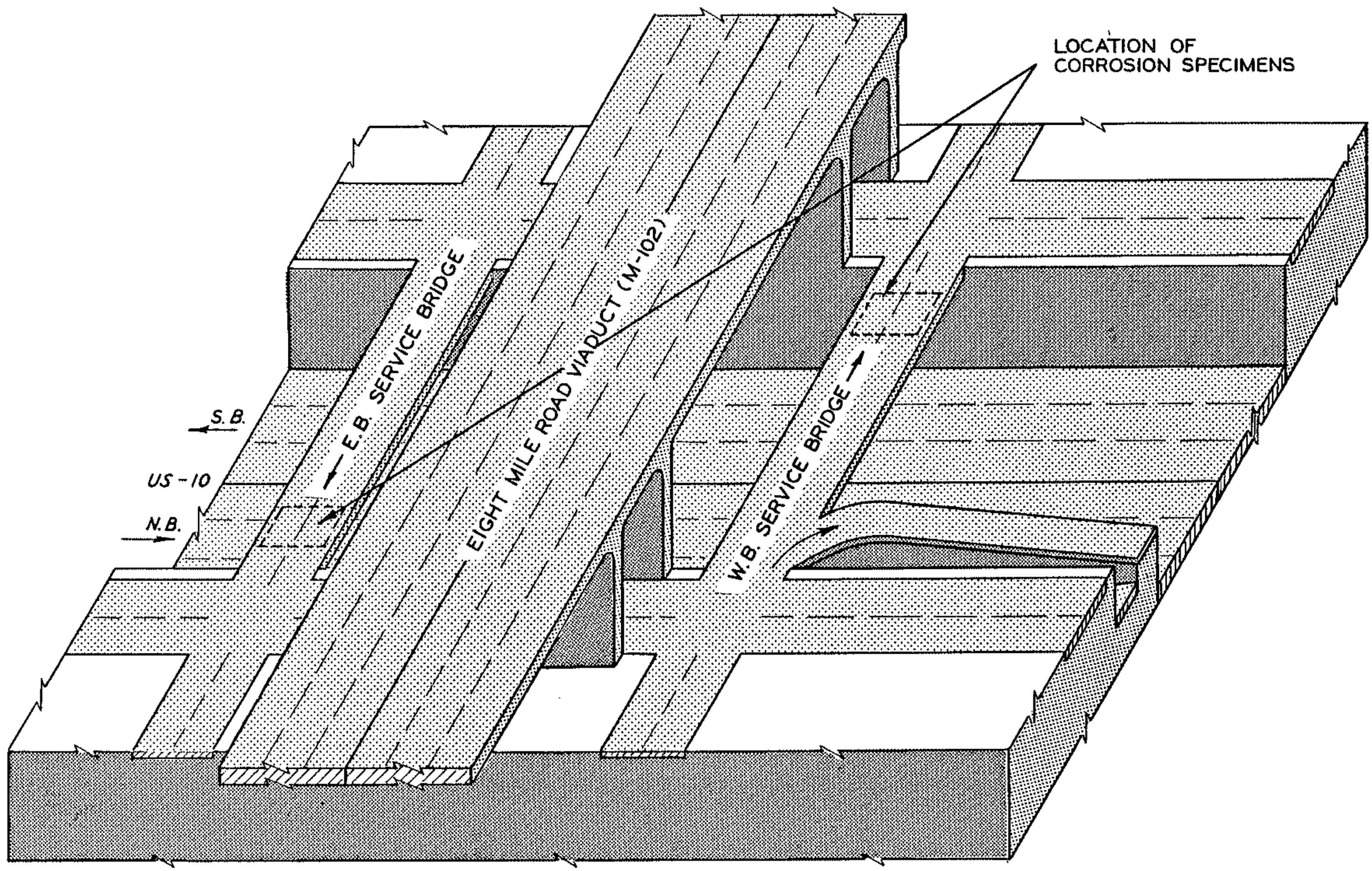

Figure 1. Complex intersection at the Eight Mile Road and the John Lodge Expressway; note location of corrosion specimens.

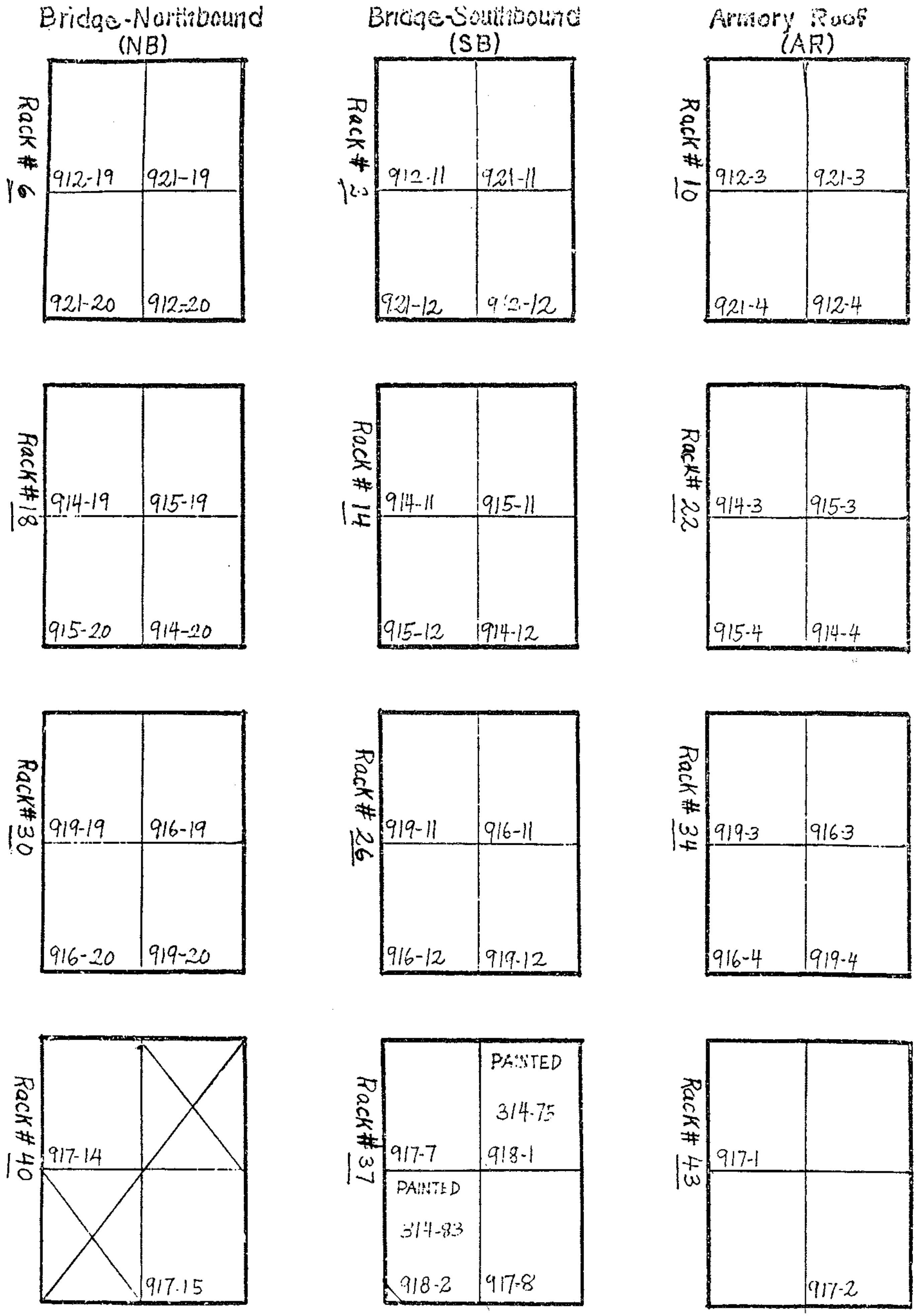

FIGURE 2. CORROSION TEST OF WEATHERING STEELS AT DETROIT, MI (Four-Year Removals)

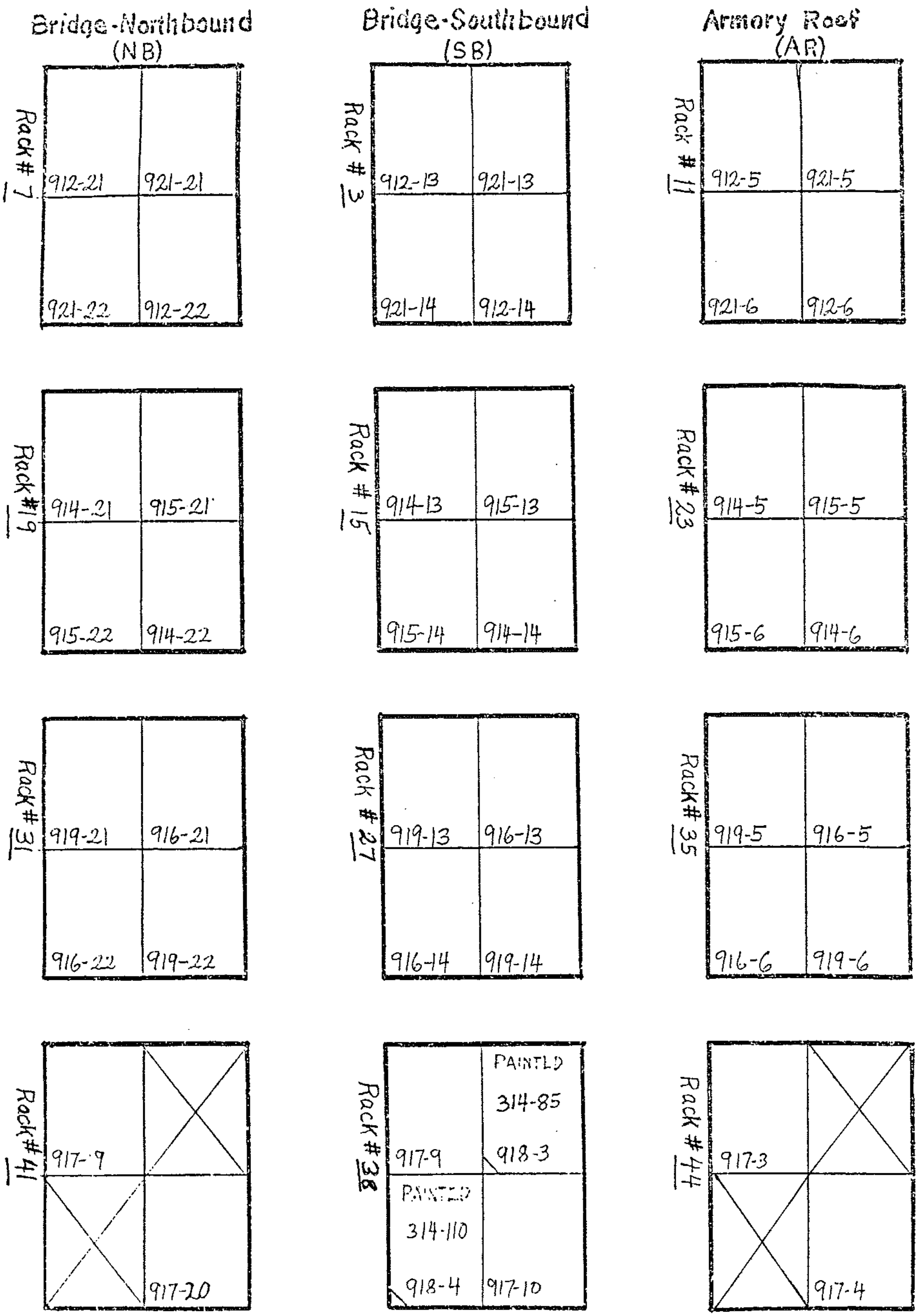

FIGURE 3. CORROSION TEST OF WEATHERING STEELS AT DETROIT, MI
(Eight-Year Removals)

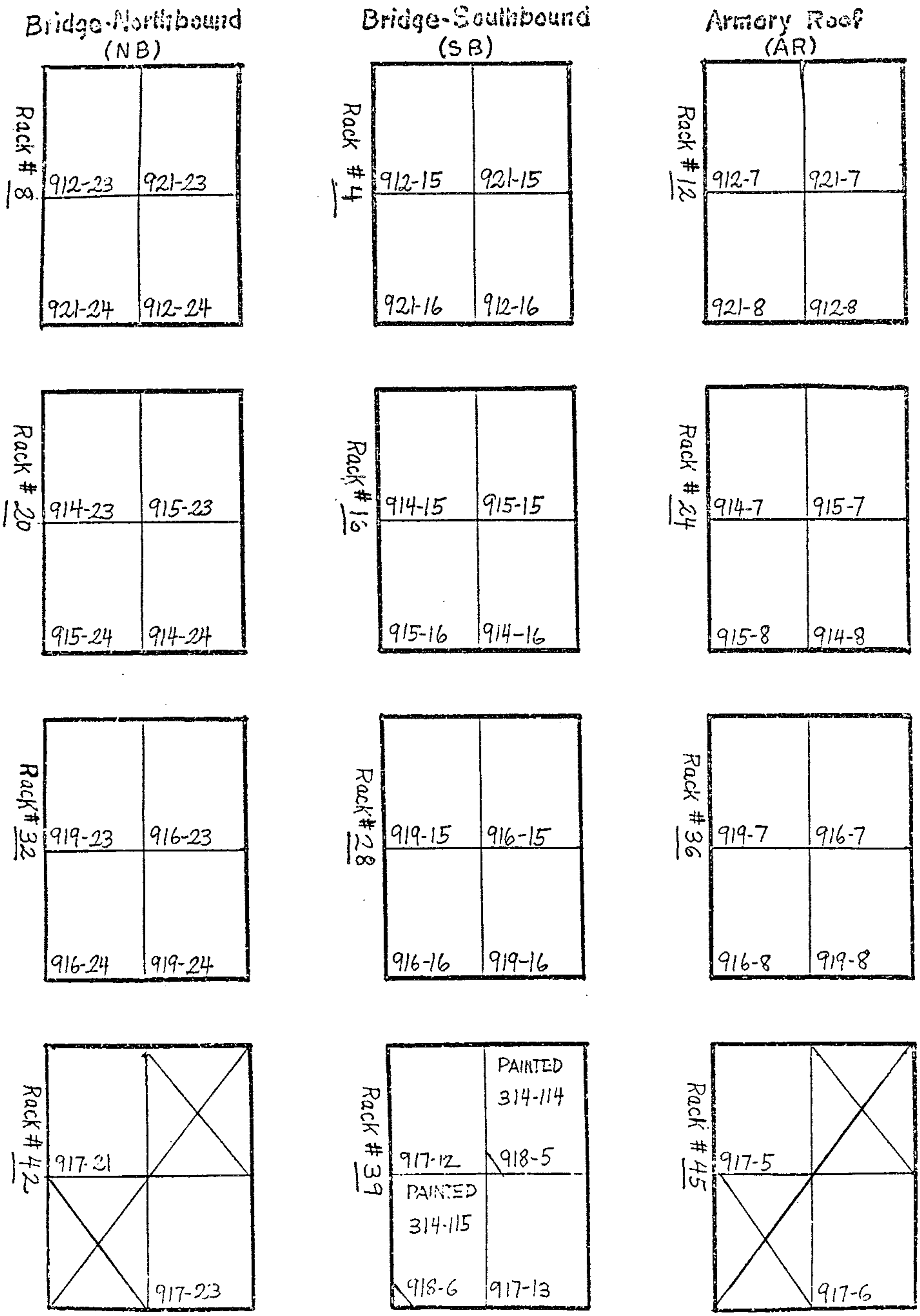

FIGURE 4. CORROSION TEST OF WEATHERING STEELS AT DETROIT, MI
(Sixteen-Year Removals)