Atmospheric Corrosion Tests of Unpainted Steels for Use in Construction of Highway Bridges

BRUCE COSABOOM and GEORGE S. KOZLOV,
New Jersey Department of Transportation; and
JAMES ZOCCOLA, Bethlehem Steel Corporation

A 1967 paper on atmospheric corrosion tests of low-alloy steels and the applicability of the test results to highway bridges concluded that further testing and research were necessary in order to clarify certain concepts. Since then, the New Jersey Department of Transportation and the Bethlehem Steel Corporation have jointly undertaken the development and implementation of corrosion tests of unpainted steels. This paper is a preliminary report on the corrosion tests and includes no data results, and therefore no formal conclusions, as yet. These tests, conducted in the industrial atmosphere of Newark, New Jersey, are intended to provide data that will aid in determining the effect of road salt spray and local corrosion factors, as well as in establishing time-corrosion curves. Rust-staining of adjacent materials (i.e., concrete bridge abutments and columns) is also accounted for in the test program.

Because of the many difficulties encountered in the procedure originally proposed, the program does not account for such concepts as stress corrosion effects, cyclic load on corrosion rate, reduction in fatigue strength, and loss of tensile strength due to corrosion. Details of the complete test program in progress are given.

•AN earlier study (1) led the New Jersey Department of Transportation to the conclusion that an atmospheric corrosion test program should be undertaken in order to study certain factors that may influence the corrosion rates of unprotected steels. Since then, this test program has been developed and undertaken jointly by the Department and Bethlehem Steel Corporation.

The purpose of the program is essentially twofold: to provide information about corrosion effects on steels for use on unpainted highway bridges, and to afford a means of correlation between the current ASTM method of atmospheric corrosion testing and the corrosion tests discussed in this paper.

In the previous report many concepts involving the corrosion of metals were studied. It was concluded that further research was necessary on the following factors:

1. t_x = the number of years of exposure required for the time corrosion curve to become essentially linear;
2. The depth of corrosion penetration into an exposed surface after t_x years;
3. The corrosion rate after t_x years;
4. The "exposure factor", a design factor that would account for the relative severity of various steel exposure conditions;

Paper sponsored by Committee on Metals in Highway Structures and presented at the 48th Annual Meeting.

5. The "pitting factor", a design factor that would account for the effect of pitting on the strength of construction steels;
6. The degree of reproducibility of results;
7. The effect of static loads on the corrosion rate;
8. The effect of cyclic loads on the corrosion rate;
9. The effect of prior corrosion on static and dynamic strength;
10. The possible effect of corrosion-fatigue and stress corrosion;
11. The effect of "other factors", i.e., different environments, submersion in water, effects of welding;
12. The appearance of rusted steel; and
13. The rust-staining of adjacent surfaces.

Many difficulties were encountered in developing the proposed testing procedures. It is for this reason that the program adopted had to be limited in scope and that it will not account for such factors as effects of stress corrosion, cyclic load on corrosion rate, and reduction in fatigue and tensile strength due to corrosion and pitting (pitting factor).

The actual program adopted jointly by the New Jersey Department of Transportation and Bethlehem Steel Corporation consists of the following:

1. Corrosion tests for sample panels of steel exposed in different locations and positions;
2. Periodical and occasional visual inspections of the bridge members of an experimental unpainted bridge; and
3. A visual survey and/or photographic record of the bridge steel and concrete supports, and a visual survey of other unpainted and painted bridges.

The experimental unpainted bridge referred to is constructed of Mayari-R low-alloy steel, which is produced by the Bethlehem Steel Corporation.

PHOTOGRAPHIC RECORDS OF BRIDGE STEEL AND CONCRETE SUPPORTS

Photographs of the experimental bridge with sample panels for corrosion tests mounted on the bridge beams are shown in Figures 1, 2, and 3. The photographs were

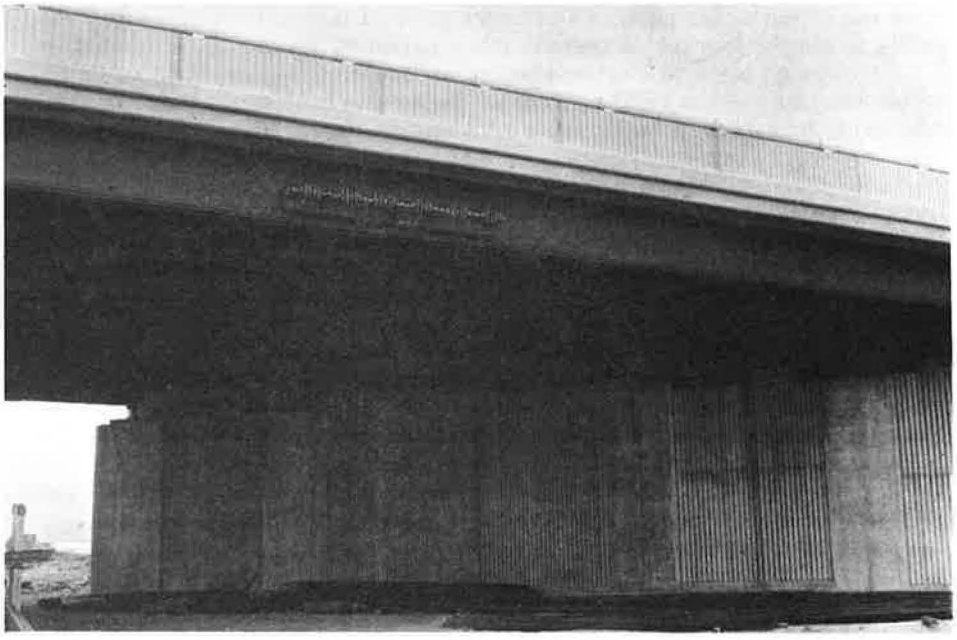

Figure 1. Bridge 9 showing location of test specimens.

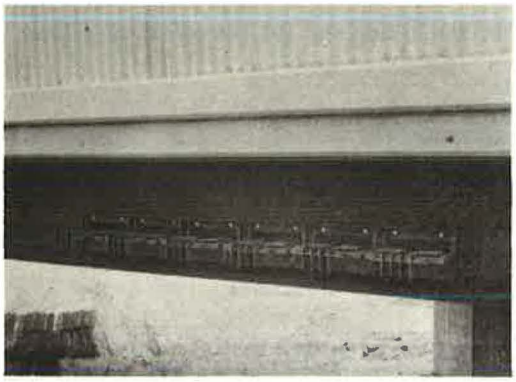

Figure 2. Sample panels mounted on bridge beam.

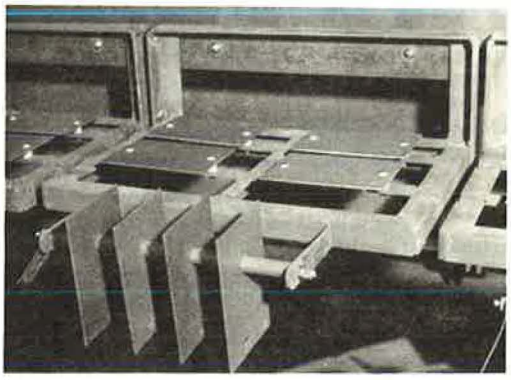

Figure 3. Mounting rack with specimens.

taken approximately 1 year after the bridge steel erection; some rust staining of the concrete abutments has appeared. The concrete had already received one chemical treatment to remove rust stains in June 1967, just after the bridge steel erection (April 1967); however, no stain-preventing measures had originally been undertaken on any parts of the bridge; i. e., the concrete had been unprotected. Additional chemical treatment of the same type is planned for the concrete abutments. The cleaning product used is a blended inhibited acidic cleaner with a penetrant. It consists of a number of compounds including sodium thiosulfate. It should be noted that this chemical treatment is a cleaning process and not a protective device for the concrete. The rust staining at the bridge is expected to diminish with time of exposure. Eventually it may reach a point at which rust staining of the concrete is no longer a problem and cleaning maintenance can be eliminated.

CORROSION TESTS

Purpose

Exposed metal sample panels are mounted at two sites and in various positions. The exposure sites were chosen for purposes of correlation of the various corrosion results with the results of similar corrosion tests in other areas of the nation. It is also intended that the corrosion tests will allow a better estimate of the time-corrosion curve of the unpainted steel and of the local "corrosion factors". Both exposure sites are in the area of Newark, New Jersey, which has an industrial atmosphere.

Scope

At the time of mounting, the surface conditions were the same for all sample panels, i.e., clean and free of all foreign matter. This was accomplished through gritblasting and a degreasing treatment. The specimens of steel are being exposed for specific periods of 1 to 16 years, and were first mounted on specific dates in May 1968. Upon removal of specimens, the weight loss due to corrosion will be evaluated and this value will be used to determine the time-corrosion curve of the unpainted steel and local corrosion conditions. The weight loss will be transformed into an average thickness loss, which is, of course, actually a loss in cross-sectional area of the specimens.

Comparison of corrosion results on these specimens will provide information on local exposure conditions. If there is nonuniform corrosion on the specimen surfaces—that is, if pitting occurs to a significant extent—then the degree of pitting and perhaps the pit depth should be recorded and evaluated.

Materials

The specimens are rolled sheet metals made of five different materials as follows: rolled zinc, plain carbon steel, Mayari-R (ASTM A-242), Mayari R-50 (ASTM A-588-Grade B), and copper-bearing steel. A percent-composition analysis is given in Table 1.

TABLE 1

TEST MATERIALS WITH CHEMICAL ANALYSIS AND CODE NUMBERS

Code Number	Material	Analysis, Percent									
		C	Mn	P	S	Si	Ni	Cr	Cu	V	Mo
503	Copper-bearing steel	0.020 0.023	0.34 0.35	0.003 0.006	0.011 0.014	0.01	0.02	0.02	0.21	–	–
504	Mayari R-50 steel	0.13	1.02	0.008	0.018	0.22	0.27	0.64	0.21	0.062	–
506	Mayari-R steel	0.09	0.65	0.11	0.032	0.29	0.66	0.52	0.27	–	0.010
507	Plain carbon steel	0.07	0.35	0.009	0.020	<0.001	0.01	0.02	0.021	–	–
N1747	Rolled zinc	–	–	–	–	–	–	–	–	–	–

Specimen Preparation

The sample panels measure 4 by 6 by $^1/_{10}$ in. with the exception of a few experimental formed-box sections. The specimens were cut from rolled sheets and mounting holes were drilled, after which all edges were machined to remove imperfections from cold-working. The surfaces were thoroughly cleaned by gritblasting and a degreasing treatment to remove all dirt, oil, grease, and other foreign matter. The specimens were identified by code numbers stamped on one surface. After cleaning, the specimens were weighed in grams with an accuracy of four places. The weights were permanently recorded. The Bethlehem Steel Corporation performed the preparation of specimens for mounting.

Specimen Mounting

The specimens were generally mounted in three different positions on the racks. A number of specimens were mounted in the horizontal plane to duplicate the position of the flanges of bridge beams. Similarly, a number of specimens were mounted in the vertical plane to duplicate the position of the webs of bridge beams. A third mounting position was also selected, at 30 deg from the horizontal plane, to conform with the standard ASTM atmospheric corrosion testing procedure.

Although the idea of vertical and horizontal boldly exposed samples was developed jointly, the actual design and manufacturing of the racks was accomplished by Bethlehem Steel research personnel. All materials for racks and specimens were supplied by that company. The installation of the racks and specimens was carried out jointly by Bethlehem Steel and the New Jersey Department of Transportation. During the process of mounting, all specimens were handled with clean white gloves. Thus, the cleanliness of the specimen surfaces at the start was ensured.

As stated previously, two different sites were selected for mounting the specimens. For the sake of clarity, details for mounting the specimens will be handled separately for each site.

Experimental Bridge Installation

The experimental bridge at Newark was constructed as part of the contract for Interstate Route 78; it is not expected to be in operation until 1972. The superstructure consists of Mayari-R steel beams supporting a reinforced concrete deck slab. The steel work was erected April 26 and 27, 1967.

Specimens of Mayari-R and plain carbon steel were mounted on three deck supports made of Mayari-R steel on May 10, 1968. Each rack is in a different location on the bridge beams, as shown in Figure 4. Figures 2 and 3 show the specimens as mounted on the racks. (Note the specimen identification numbers in Figure 3). A total of 144 specimens were mounted: 72 panels are vertical, the other 72 horizontal. Half of the panels in each position are plain carbon steel, the other half are Mayari-R steel. Care

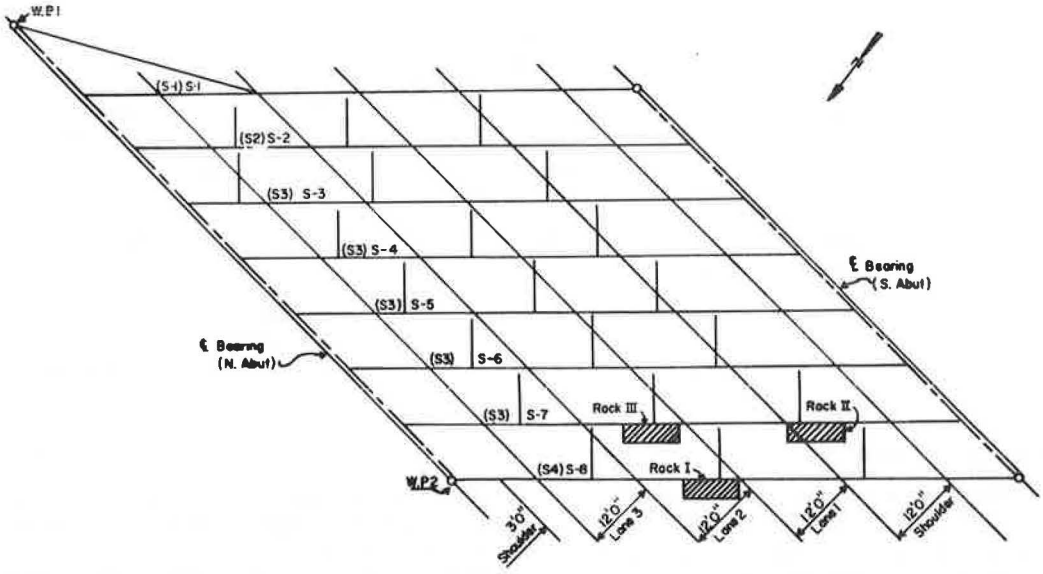

Figure 4. Location of test racks with respect to the bridge stringers.

was taken to ensure that the supports were mounted horizontally, so as to ensure horizontal and vertical positioning of the sample panels, as desired.

As shown in Figures 1 and 4, the group of specimens of Rack I is located on fascia beam (S4) S-8, directly over the central area of the roadway. These specimens are boldly exposed to receive the full effects of rainfall and direct sunlight.

Rack holder II is located on beam (S3) S-7, over the shoulder area of the roadway. This interior position, sheltered from the cleansing effect of rain and slower to dry, will duplicate conditions that have led to increased corrosion of low-alloy steels in other applications. Rack holder II should receive maximum amounts of road salt spray, dirt, fumes, etc., from vehicles passing under the bridge.

Rack holder III is also located on beam (S3) S-7. It is placed over the central area of the roadway and should experience the effects anticipated from a sheltered location. However, it should not receive the maximum amounts of spray from passing vehicles.

Through the selection of these specimen locations on the bridge, the salt-spray effect is designed into the corrosion tests. The test specimens are not specifically located to allow exposure to salt water running off the bridge, as would be experienced at an expansion joint. Due to practical limitations, this specific test is not thought to be feasible.

It is worth noting at this point that these specimens, because of their horizontal and vertical positioning, do not permit direct correlation with standard atmospheric corrosion tests in the literature. To facilitate such correlation, standard specimen orientation was provided at a second installation on the roof of a nearby building. The horizontal and vertical specimen positioning at the bridge site was chosen, as stated before, to duplicate the orientation of the flanges and webs of bridge beams.

Roof Installation

The test rack for the roof installation is located on the roof of a New Jersey Department of Transportation maintenance garage in Newark, very close to the experimental bridge site. The test rack is shown with specimens in Figure 5. Notice that the rack allows for mounting of specimens in vertical and horizontal directions, as well as a position at 30 deg from the horizontal. This is important since most ASTM atmospheric corrosion tests use an incline of 30 deg-from-horizontal as a standard exposure position

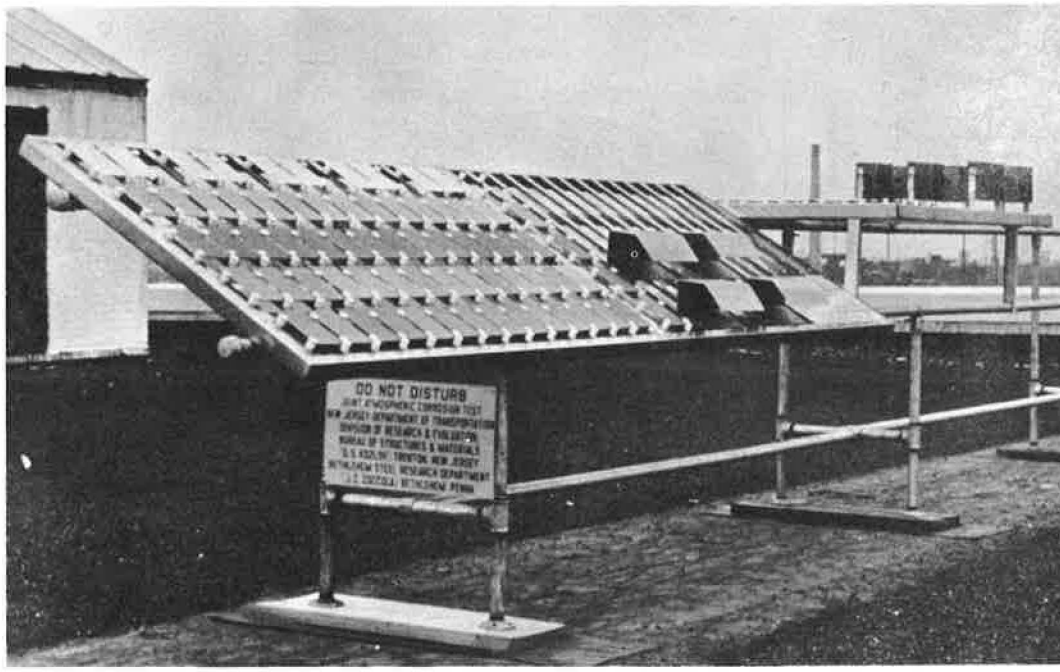

Figure 5. Roof installation of specimens.

for sheet products. The test rack was purposely constructed longer than necessary, to accommodate any possible additional specimens for installation at a later date. The specimens shown in Figure 5 were installed on May 15, 1968.

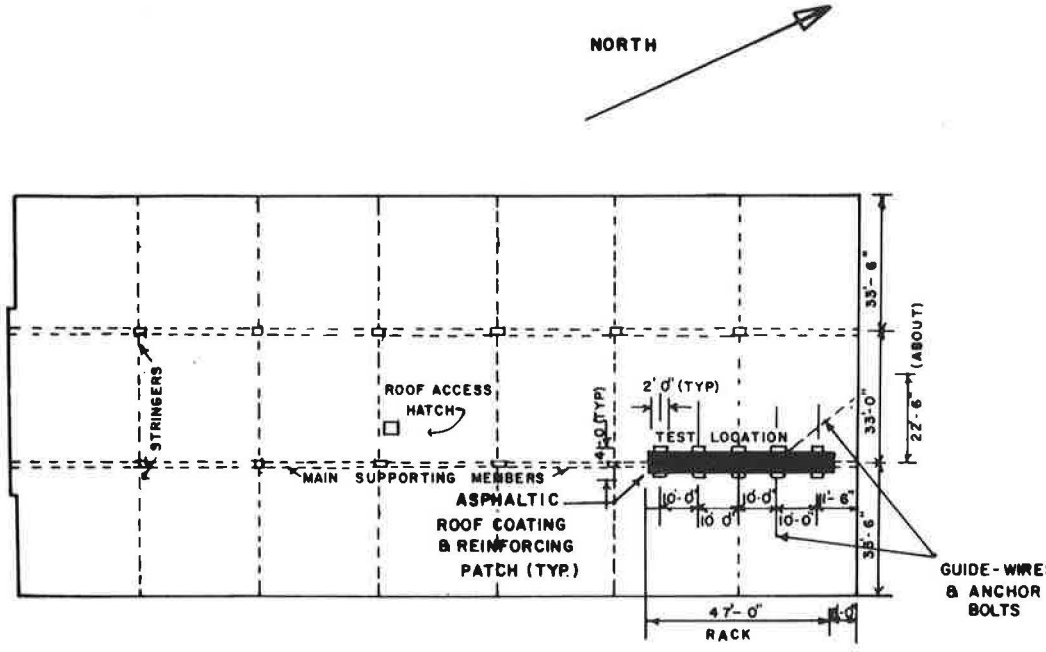

Figure 6. Roof framing plan showing location of test rack.

TABLE 2

SCHEDULE OF INSTALLATION AND REMOVAL OF TEST SPECIMENS

Exposure Site	Material	Specimen Orientation	Installations (Years After Init. Date)[a]	Removals (Years After Init. Date)[a]	No. of Specimens						Total No. of Specimens
					Installed			Removed			
					Hor.	Vert.	30 deg	Hor.	Vert.	30 deg	
Bridge 9 over Route 1-78, Newark, New Jersey	Mayari-R and plain carbon	Vertical and horizontal	Initial date	-	72	72	-	-	-	-	240
			x	-	48	48	-	-	-	-	
				1	-	-	-	12	12	-	
				2	-	-	-	12	12	-	
				4	-	-	-	12	12	-	
				x	-	-	-	12	12	-	
				x + 1	-	-	-	12	12	-	
				x + 2	-	-	-	12	12	-	
				8	-	-	-	12	12	-	
				x + 4	-	-	-	12	12	-	
				x + 8	-	-	-	12	12	-	
				16	-	-	-	12	12	-	
Dept. of Transportation garage roof, Newark, New Jersey	Mayari-R and plain carbon	Vertical and horizontal	Initial date	-	24	24	-	-	-	-	80
			x	-	16	16	-	-	-	-	
				1	-	-	-	4	4	-	
				2	-	-	-	4	4	-	
				4	-	-	-	4	4	-	
				x	-	-	-	4	4	-	
				x + 1	-	-	-	4	4	-	
				x + 2	-	-	-	4	4	-	
				8	-	-	-	4	4	-	
				x + 4	-	-	-	4	4	-	
				x + 8	-	-	-	4	4	-	
				16	-	-	-	4	4	-	
	Mayari-R, plain carbon, Mayari-R-50, Cu-bearing, rolled Zn	30 deg from horizontal	Initial date	-	-	-	70[b]	-	-	-	70[c]
				1	-	-	-	-	-	14	
				2	-	-	-	-	-	14	
				4	-	-	-	-	-	14	
				8	-	-	-	-	-	14	
				16	-	-	-	-	-	14	

[a]The "x" installation and removal will occur after the bridge and highway below the bridge are opened to traffic.
[b]In addition to these panels, small formed box sections are being exposed for appearance of each type of metal.
[c]One of these panels will be held for possible display.

The location of the test rack on the roof (Fig. 6) was dictated by two factors. First, the structural features of the garage require that the rack be aligned over a main supporting member to minimize the effect of the increased load. Second, the location was selected to be as far as possible from any vents or stacks that might emit fumes that would abnormally influence the corrosion rates on any of the specimens. The rack has a northeast-southwest orientation, the specimens facing 10 deg east of south. This deviates slightly from the standard ASTM exposure tests, in which the specimens face due south.

With the mounting of these specimens, two direct correlations will be obtained. First, corrosion rates of the specimens with a 30-deg slope may be correlated with rates of specimens tested elsewhere in the nation according to ASTM methods. Second, corrosion rates of horizontal and vertical specimens may be correlated with rates of specimens on a 30-deg slope. An indirect correlation may then be obtained between horizontal and vertical tests in Newark and standard ASTM corrosion tests anywhere in the nation.

Number and Type of Specimens

The position, type, and number of specimens on each rack at each location have been permanently recorded. The following is a summary of all the specimens to be installed during the 16-year test period:

1. 240 test specimens of Mayari-R and plain carbon steel, arranged vertically and horizontally in sets of 8 specimens, shall be located on the bridge.
2. 80 specimens of Mayari-R and plain carbon steel, arranged vertically and horizontally, shall be located on the garage roof.
3. 70 specimens of Mayari-R, plain carbon, Mayari R-50, copper-bearing, and rolled-zinc materials placed at 30 deg from horizontal, shall be located on the garage roof.

The future placement of additional specimens on the garage roof test area will be a joint decision of the participating organizations.

The foregoing description of test specimens includes the total number of specimens for the 16-year test period. Not all of the specimens have been installed initially. Remaining specimens will be installed at predetermined intervals. A schedule of installations and removal of specimens is given in Table 2. Note that a number of specimens are to be installed when the experimental bridge and the highway below the bridge are opened to traffic. This is to test the salt spray effect on the unpainted steel.

CONCLUDING COMMENTS

At the time of the preparation of this paper, the test program has only been initiated. A few points are, however, worth noting:

1. Cleaning maintenance has been necessary on the concrete bridge abutments because of rust-staining. And, to date, further cleaning will be required although it is not known for how long. On the basis of future results, it may or may not be wise to consider application of a protective covering to adjacent surfaces. Of course, to begin with, the run-off water should be kept away from the piers and abutments, thus preventing staining.
2. Although the specimens were mounted approximately 1 year after the bridge steel erection, and they have only been mounted for a few months, they have already blended very well in color with the bridge steel, which is rustic in appearance.
3. The test program began very well and no special problems are anticipated.

Later progress reports will include test results and data with details of the handling, cleaning, weighing, and examination of the specimens and any other pertinent information.

REFERENCE

1. Division of Research and Evaluation, Bureau of Structures and Materials, State of New Jersey, Department of Transportation. An Analysis of Atmospheric Cor-

rosion Tests on Low-Alloy Steels—Applicability of Test Results to Highway Bridges. Highway Research Record 204, pp. 22-45, 1967.

Discussion

JOHN R. DAESEN, The Galvanizing Institute—We believe the test of unpainted steels by the New Jersey Department of Transportation and Bethlehem Steel Corporation misses its objective, because of the form of test material chosen.

Because the need for evaluation of effect of corrosion on dynamic strength, corrosion fatigue, and stress corrosion is recognized by the present authors, as well as in the 1967 paper, the choice of $^1/_{10}$-in. thick rolled sheet to predict performance of structural steel shapes for bridges can hardly be approved. It is well known that surface soundness, structure, and homogeneity strongly influence the effects of corrosion, with or without stress, and these surface conditions are by no means equivalent in $^1/_{10}$-in. thick rolled sheet and structural shapes with up to $^3/_4$-in. thickness of section.

The effect of these differences on pitting effects, if not on general corrosion rate, cannot be disregarded, because local centers of accelerated corrosion are potential stress raisers.

Results of corrosion tests on sheets of comparable compositions in many environments have already been published and compared. The only new values to be obtained in this test are the effect of shading from the sun and rain, and the effect of contaminated spray from the roadway. It is just these conditions that should intensify the effect of surface inhomogeneity or variable structure. The "pitting factor" found in sheet cannot be expected to be representative of the surface of bridge structural members.

We feel, therefore, that the test should have used material from commercial beams for bridges. To meet the needs of weighing, the test samples should be planed down to $^1/_{10}$-in. thickness, leaving intact one original commercial surface, as received. The edges and reverse surface could be masked off. After exposure, the simplest of dynamic or fatigue tests on specimens so prepared would be invaluable in demonstrating the advisability of more elaborate tests.

Of less importance, but in the same vein, we suggest that the so-called A 36 plain carbon steel, with 0.07 and carbon, 0.35 manganese, less than 0.001 silicon, and 0.021 percent copper, is not a composition that would develop the strength of the other steels tested, and may well be not representative of the corrosion resistance of plain carbon steel bridge beams.

Similarly, the use of rolled zinc, obviously intended to represent the performance of galvanized steel, is an error that can only mislead. More than half of the thickness of the galvanized coating on such steel as is used for bridges is zinc-iron alloy, with corrosion resistance in unshielded industrial exposure superior (by some 30 to 40 percent) to that of zinc (as reported by me in "Corrosion Resistance of Galvanized Coatings," Second International Congress on Metallic Corrosion, page 699).

Demonstrating the nature and extent of variability of surface structure and corrosion in rolled structural sections, Figures 7, 8, and 9 show irregular attack on a 2 by $^1/_4$-in. low-alloy steel angle, exposed 10 years in an industrial atmosphere. The steel analyzed 0.08 carbon, 0.39 manganese, 0.125 phosphorus, 0.39 silicon, 0.59 chromium, 0.22 nickel, and 0.33 percent copper. This is typical of the "slow rusting" steels. The bevel at a sawed edge, Figure 7, filed at 30 deg to the corroded surface, indicates the irregularity of attack. The complex nature of the rust layer shown in the "as polished" cross sections, Figures 8 and 9, indicates the importance of structure at the surface in setting up stress-raising pits.

Figures 10, 11, and 12 show massive slabs of "rust" up to $^1/_4$-in. thick formed on a railway station column built of 6 by 6-in. steel angles "protected" by aluminum paint. The hydrated oxide material is magnetic, but is seen to be entirely nonmetallic, and the structure of the "as polished" cross sections suggests how the progress of corrosion has varied with local differences in structure of the steel, even well below the immediate

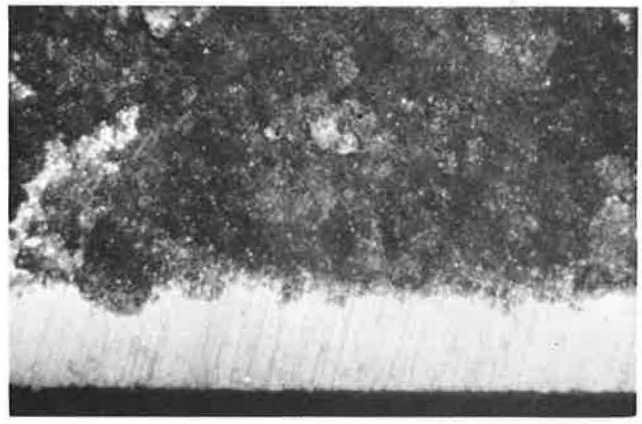

Figure 7. Low-alloy angle, surface, 15X.

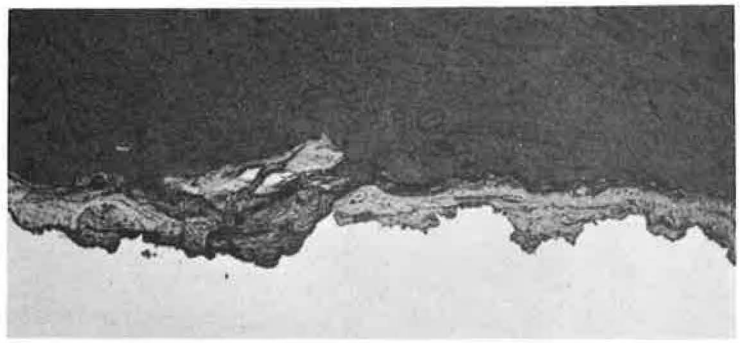

Figure 8. Low-alloy angle, cross section, 100X.

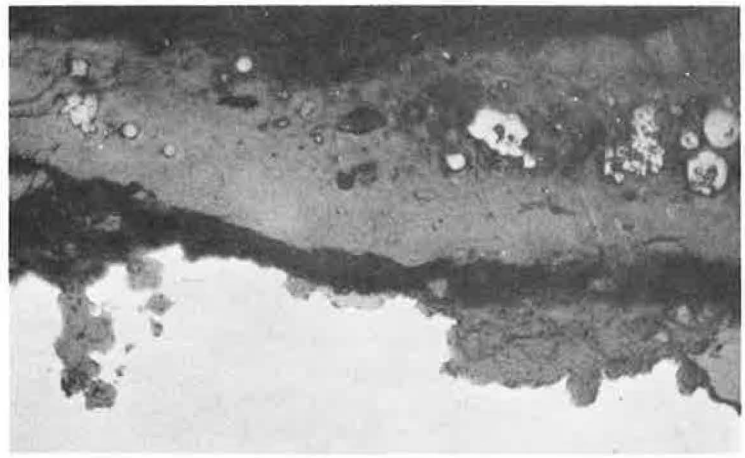

Figure 9. Low-alloy angle, cross section, 500X.

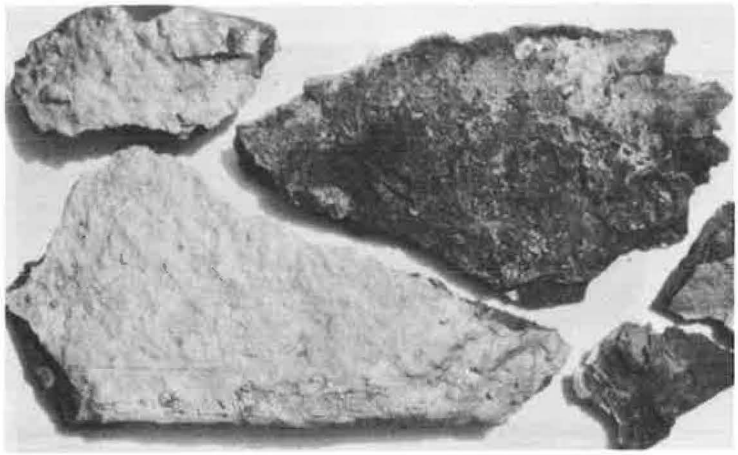

Figure 10. Massive rust buildup; $^4/_5$ natural size.

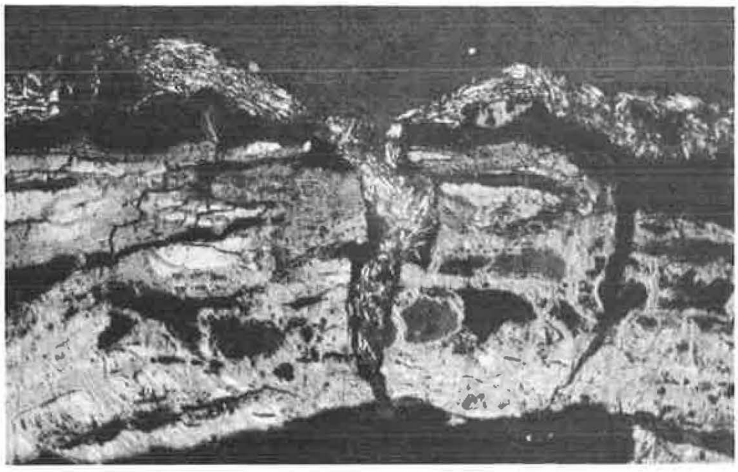

Figure 11. Rusted section at surface, 100X.

Figure 12. Rusted interior section, 100X.

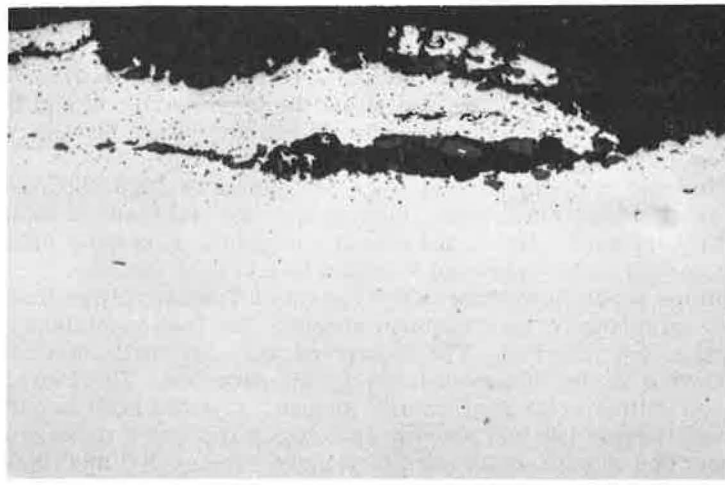

Figure 13. Sliver of 8-in. beam as received, 100X.

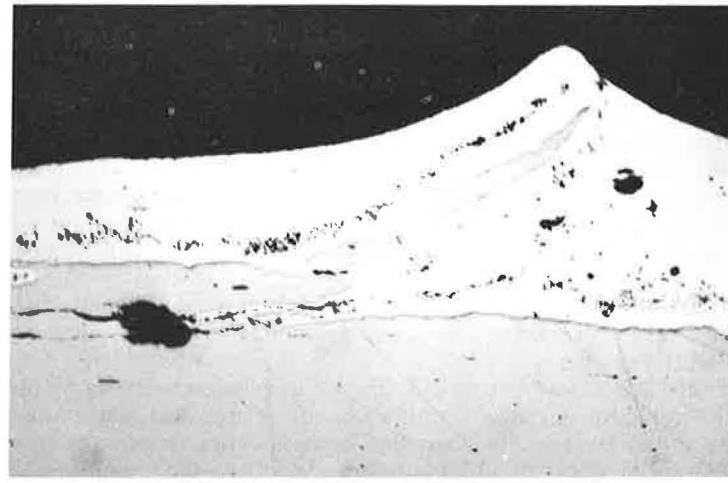

Figure 14. Sliver after galvanizing, 100X.

surface. Such massive rust is not uncommon under paint. This demonstrates that an intact coating of hydrated magnetic oxide can permit continued corrosion to complete destruction.

Finally, Figure 13 shows in cross section a small sliver from the surface of an 8-in. wide flange beam of A 36 plain carbon steel, illustrative of surface defects found in massive sections, and less prevalent in $^1/_{10}$-in. thick rolled sheet. Figure 14 shows how molten zinc, in galvanizing, searches out (as corrodents do) these defects, lifting the overlapping steel.

This discussion is offered to suggest the need for more realistic planning of tests that are designed to indicate performance of exposed structures against corrosion, and to urge the New Jersey Department of Transportation to amend their corrosion tests on material under consideration for highway bridges.

BRUCE COSABOOM and GEORGE S. KOZLOV, Closure—It is our opinion that the discussion is, in part, not pertinent, and is generally incorrect.

The discussion directly attacks the material that is being tested as well as the research that is presently being conducted jointly by the Department and Bethlehem Steel. It is our intent to refute certain points of the discussion, while leaving other points to be refuted by Bethlehem Steel.

Daesen states that a $^1/_{10}$-in. thick rolled sheet cannot be used to predict performance of structural steel shapes for bridges, making specific reference to factors such as dynamic strength, corrosion fatigue, and stress corrosion. It is quite clearly stated in the paper that the corrosion tests are not intended to test such factors.

It is the opinion of the New Jersey Department of Transportation that the material in these tests is representative of structural shapes. The test specimens actually came from structural shape material. The specimens were originally much thicker, but they were rolled down to $^1/_{10}$-in. thickness for weighing purposes. Therefore, the material chosen is indeed the material of structural shapes. In addition, it is our opinion that the surface conditions of the test specimens actually represent those of structural shapes: the specimens were gritblasted to remove surface dirt and imperfections. The low-alloy structural shapes were also gritblasted on the New Jersey experimental bridge, and Bethlehem Steel similarly recommends this process for all low-alloy steel to be used on bridges.

Therefore, it is our opinion that the tests by the Department and Bethlehem Steel do not miss their objective (as the objective is stated in the paper), because of the form of test material chosen. It is our opinion that the information gained concerning the extent of corrosion and pitting for a zero-stress condition will be valuable, accurate, and pertinent.

The Department is interested in low-alloy steel from the user's point of view. We feel that the severe industrial location, in addition to the salt spray and sheltering, as mentioned in the paper, is quite pertinent to our purposes. We also feel that these effects are important to other users of low-alloy steel. Daesen contradicts himself when in one sentence he discredits our research and the next sentence spells out the importance of certain factors; indeed, factors which in our opinion will be accounted for in our tests.

Again, we feel that the surface of our test specimens could hardly be more representative of the surface of bridge structural members. However, this point should be discussed by Bethlehem Steel.

Daesen attacked the use of rolled zinc in our corrosion tests as an obvious intention to represent the performance of galvanized steel. There was and is absolutely no such intention. If we did entertain this idea, then zinc specimens most certainly would have been installed on other racks in other positions, i. e., on the experimental bridge racks. Rather, it should be noted that very few zinc specimens were used; they were installed only at the roof location, and only in the 30-deg slanted position. These specimens are to serve only as a method of correlating the roof site with other ASTM corrosion-test sites.

Daesen refers to the thick rust coating that existed on steel angles "protected" by aluminum paint. He demonstrates that rust commonly exists under paint. We are sure that this piece of information is well known. (We are equally certain that it has nothing to do with our corrosion tests!) Daesen also concluded "that an intact coating of hydrated magnetic oxide can permit continued corrosion to complete destruction"—on regular steel. He has given no information on low-alloy steels. Bethlehem Steel claims that the rust coating on low-alloy steels will protect the underlying steel to a large extent—enough to warrant the unpainted use of such steels. We are aware that severe rusting will continue on regular steel, if allowed. However, Daesen has not shown evidence of such continued deep rusting on the low-alloy steels. He has not given negative or positive evidence concerning the claim of Bethlehem Steel on low-alloy steel. And this is exactly one area in which we believe that our joint corrosion tests will yield valuable information. Where Daesen has used the results of one material to imply something of another

material, we intend to imply nothing, and cautiously obtain results on the material in question.

Daesen demonstrates how molten zinc searches out defects in surfaces of structural steel members. This can hardly be regarded as pertinent to the subject matter.

In summary, we believe that our existing joint corrosion tests are indeed realistic and will yield valuable information. We believe that Daesen's discussion is not pertinent on a few points, and is incorrect on others. We realize that our tests do not account for certain important factors. Unfortunately, we are limited through one cause or another in our ability to carry out additional and extensive research beyond that which exists. However, this does not discredit the existing research, and it is our belief that no amendments are necessary in the material being tested.

JAMES ZOCCOLA, Closure—I concur with the comments made by Kozlov and Cosaboom in rebuttal to Daesen's discussion. The following are some additional aspects that should be mentioned.

The composition, surface, and structure of the weathering steels exposed as $^1/_{10}$-in. sheet should be well representative of plate and structurals in regard to their corrosion performance. It is not necessary nor practical in this test to machine down structural plate, mask the edges, or reverse surface. The surface was typical (gritblasted), as were the bridge members, as recommended in order to obtain a uniform, pleasing, weathered appearance.

Daesen's discussion of surface conditions such as laps is not relevant since this type of defect is rather rare and its significance in weathering behavior is questionable. Also, special racks were designed and fabricated to openly expose both top and bottom surfaces. We realize the carbon content is slightly lower than normal in the plain carbon and copper-bearing steels. But it is well known that the carbon content, in the small amounts we are discussing, has no effect on the atmospheric corrosion resistance of the steels.

The pitting behavior will not be disregarded and is to be evaluated, as stated in the paper. However, from our long-term atmospheric studies of the corrosion performance of weathering steels, we do not believe pitting will be significant.