Corrosion Performance of Weathering Steel Structures

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Weathering steels are a special class of structural steels that have been commercially available since the 1960s. These steels are intended for unpainted atmospheric exposure applications such as highway bridges, buildings, and similar structures. Despite generally favorable performance in many applications, failure of weathering steel highway bridges and other structures has been noted. Compared in this paper are the performance of weathering steel highway bridges and the performance of other weathering steel structures. Explanations are offered for why weathering steel has performed well in some applications and why it has proved unsatisfactory in other circumstances.

Weathering steels are a special class of high strength, low alloy (HSLA) structural steels developed for their resistance to atmospheric corrosion. Despite their generally favorable performance in many applications, there have been widely publicized problems with some weathering steel structures *(1, 2)*. This led to a ban on their use on Michigan highways in 1979 *(3, 4)*. Since that time other states have also banned their use for highway bridge applications.

Early reports describing the use of weathering steel mentioned several limitations on their use *(5, 6)*. Unfortunately these limitations were not widely recognized, and many structures were built having features unsuitable for use with unpainted weathering steel.

Recent reports on weathering steel have emphasized problems with highway bridges *(1, 2, 7)*. Similar problems with weathering steel buildings have not been documented in the North American literature, but some European information is now becoming available. Compared in this paper is experience with weathering steel for all types of structures in an attempt to identify reasons why the materials have performed well in some applications and poorly in others.

EARLY DEVELOPMENTS

Weathering steels were developed using standard ASTM test procedures for determining atmospheric corrosion resistance of alloys. Figure 1 shows a typical atmospheric exposure test site with flat panel specimens exposed at an angle (neither vertical nor horizontal). While a number of other atmospheric corrosion test arrangements are possible, the specimen geometry and exposure methods shown in Figure 1 were used for most of the research and development testing for weathering steels *(2, 8)*.

Test panels exposed to atmospheric corrosion in racks like those shown in Figure 1 can be analyzed in a number of ways. Corrosion products can be analyzed *(9, 10)*. More often, however, these corrosion products are stripped from the sample and the remaining metal is weighed. Weight loss data can be reported directly, but more often it is converted to average penetration rates. This is the type of information reported in most handbooks *(8)*. Unfortunately, these data can be misleading because they do not identify localized weight loss (e.g., pitting) and they do not differentiate between the weight loss on the top of the sample and the weight loss, usually more, experienced on the underside of the same panel.

Figure 2 shows corrosion of the lower half of an I-beam that was exposed to atmospheric corrosion. The vertical web has corroded more at the bottom than at the top. The reason for this is quite simple: some of the corrosion products falling from the upper portions of the vertical web accumulated at the bottom and provided a moisture trap that kept the steel at the bottom wet for longer periods of time. This wetter steel corroded more than adjacent well-drained surfaces. Corrosion of complex-geometry weathering steel structures will not be uniform, as illustrated by Figure 2. Thus extrapolations of service life based on exposures of simple flat specimens may be misleading and may not predict the accelerated corrosion experienced on actual structures.

All of the information already cited is widely known and well documented in the literature on corrosion. It is not well known in the construction community, however. The engineers

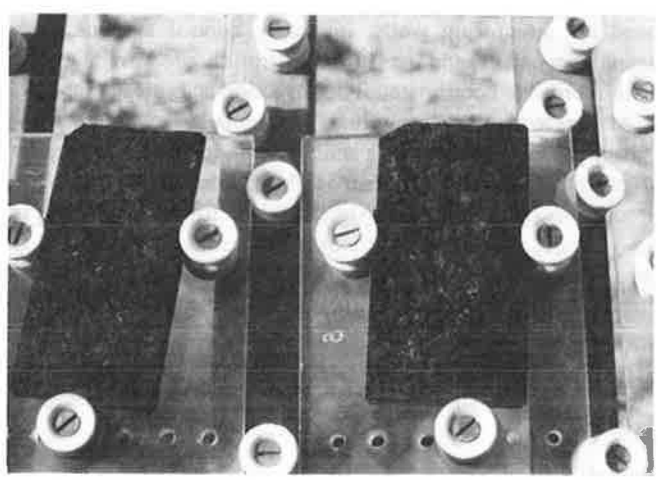

FIGURE 1 Corrosion test panels at atmospheric corrosion test site, Kure Beach, N.C.

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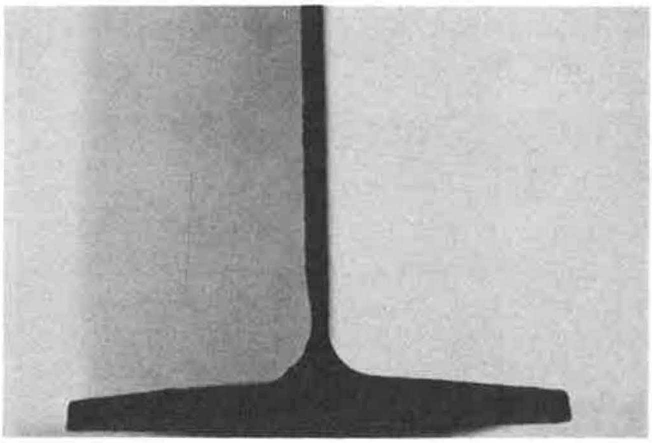

FIGURE 2 Corrosion of lower half of weathering steel I-beam exposed to atmospheric corrosion.

who specify materials and design structures made from weathering steel can readily appreciate, but are unlikely to be aware of, the point discussed here.

The first weathering steel buildings and highway bridges were built in the early 1960s. Articles have appeared in the metallurgical literature explaining the advantages, and limitations, of these new materials *(8)*. More important, similar articles appeared in the construction industry literature. In one such article, Madison described the development of weathering steels, showed atmospheric corrosion rate data obtained from flat panel specimens, and described applications in buildings, highway bridges, guard rails, and other structures *(5)*.

Madison's article cautioned that weathering steel should not be used submerged or buried in the ground—applications where the metal surface could not dry out periodically and form a protective rust coating. Madison's article also discussed welding, and bolts, and so on.

A similar article by Coburn *(6)* cautions against crevice corrosion, condensation on the interior of wall panels, and includes other suggestions not covered in Madison's article. Thus, many of the limitations of weathering steels were recognized in the 1960s, but they were not readily available to the construction community, as opposed to the metallurgical community.

The potential cost savings of weathering steel, and the apparent success of many weathering steel designs, led to widely publicized applications of this new material. By 1969, an award-winning weathering steel design was featured on the cover of *Civil Engineering* magazine *(11)*.

HIGHWAY STRUCTURES

The Michigan ban on the use of weathering steels led to a number of surveys on the performance of weathering steel highway structures in the United States and Canada.

One of the first comprehensive surveys of weathering steel highway bridges was conducted by a task group organized by the American Iron and Steel Institute (AISI) *(3)*. This report showed a number of bridges, representative of weathering steel bridges in the northeastern United States (North Carolina to Wisconsin), and most were in excellent shape. Drainage problems that resulted in loose, nonprotective rust were described on bridges in Michigan, New Jersey, and North Carolina. The rust from one Michigan bridge contained 1.15 percent chloride at a location where no significant section loss was noted.

The generally favorable results of the AISI report can be contrasted with other reports of widespread problems. For example, inspections in Ontario revealed extensive corrosion problems that could be correlated with poor drainage *(7, 12)*. This is the most common source of corrosion problems on weathering steel structures *(2)*. The examples that follow illustrate some of the problems with weathering steel that have been identified.

Figure 3 shows laminar corrosion on a horizontal bridge member from the New Jersey Turnpike. Other areas on the same bridge were in generally good condition with no evidence of loose, flaky rust or progressive corrosion. This highway is heavily traveled and receives heavy salt applications *(3)*. The corrosion shown in Figure 3 is due to poor drainage and not to deicing salts—if deicing salts were causative, other portions on the same bridge would have had the same problem.

Some problems with weathering steels can be related to improper storage before construction. Figure 4, photographed

FIGURE 3 Laminar corrosion on poorly drained horizontal surface of New Jersey Turnpike highway separation bridge.

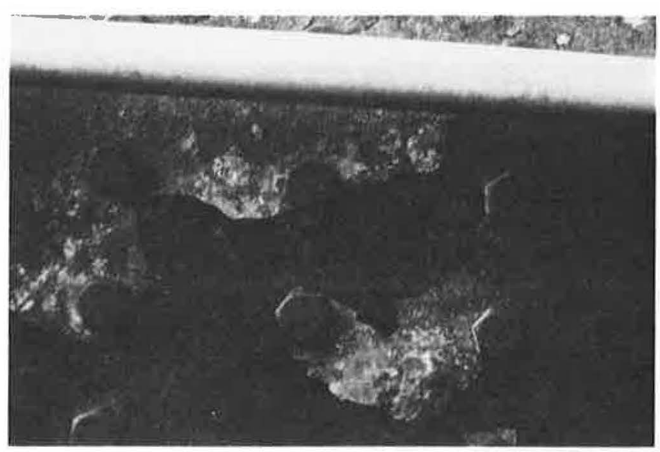

FIGURE 4 Loose, flaky rust on interior surface of Luling Bridge across the Mississippi River near New Orleans.

during bridge construction in 1983, shows loose, flaky rust on the Luling Bridge across the Mississippi River near New Orleans. Prewelded box sections of this bridge were shipped across the ocean on the deck of a ship. The corrosion shown in Figure 4 started during the shipping process and cannot be attributed to the environmental conditions at the bridge site.

Figure 5 shows safety nets used during sandblasting operations before painting on the Dollut Canal bridge, a smaller highway bridge south of New Orleans. This bridge was involved in a widely publicized lawsuit between a painting contractor and the Louisiana Department of Transportation *(13)*. The condition of the steel on this bridge was alleged to be worse than that of conventional painted bridges and to require more sandblasting, painting, and so on, than other bridges *(13)*. The steel surfaces are shown in Figures 6 and 7. The rough surface can be noted, even on the vertical members where debris cannot accumulate, as can the discoloration from the galvanized steel bolts used to mount the sample rack on the bridge.

Galvanized steel hardware is also shown in Figures 4 and 7. Although this hardware is not as rusty as the nearby weathering steel, it is obvious that it is also weathering, and galvanizing would not be a permanently protective coating for these harsh, moist environments.

Figures 3 to 7 show examples of the corrosion widely reported to occur on highway bridges. Other examples are also available *(1, 2, 7, 12)*. Corrosion of this type is commonly ascribed to the presence of deicing salts or marine atmospheres (i.e., chlorides). The fact that other locations on some of these structures do not experience excessive corrosion in the presence of these salts is seldom discussed. The fact that painted structures would experience similar problems under some of these circumstances is also often not addressed. Manning *(12)*, Albrecht et al. *(2)*, and others have discussed similar problems on weathering steel bridges, but comparisons with painted structures are not common.

OTHER STRUCTURES

The corrosion patterns on buildings, statues, and other nonhighway structures can offer clues to why corrosion has occurred on weathering steel highway bridges.

FIGURE 5 Safety nets below Dollut Canal bridge in Louisiana.

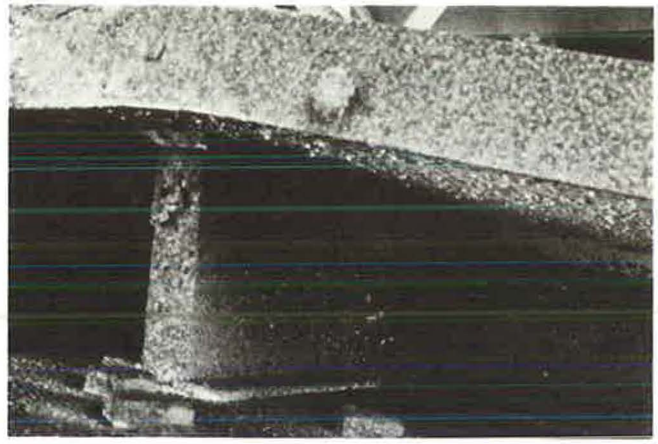

FIGURE 6 Rusty surfaces on bottom of Dollut Canal bridge before sandblasting.

FIGURE 7 Flat horizontal test panel located underneath Dollut Canal bridge.

In the 1960s many buildings were designed with weathering steels, and the designs and buildings received widespread publicity *(5, 6, 11)*. Problems associated with weathering steel buildings and statues are not well documented. One of the reasons for this is that building ownership in the United States is localized, and no central organizations (government, professional societies, and so on) are responsible for analyzing and publicizing the problems of building materials or designs. Another reason for the lack of documentation is that some of these buildings are involved in litigation, and participating parties are discouraged or prevented from publicizing their analyses.

Painting the inside of steel panels to protect against corrosion was recommended in the 1960s *(6)* but these recommendations were not always followed. Figure 8 shows corrosion from the inside out on the exterior wall panels of a university building in Illinois. These wall panels, which were not painted on the inside, corroded from the inside because of trapped condensation collecting on the inside metal surface. Corrosion damage occurred at locations where breaks in the plastic foam insulation prevented drainage. This type of weathering steel wall panel is no longer manufactured.

Figure 9 shows a public theatre in Texas that won an American Institute of Steel Construction (AISC) design award in 1969 *(11)*. Figures 10 and 11 are closeup views of the roof where

FIGURE 8 Weathering steel wall panel that corroded from the inside out.

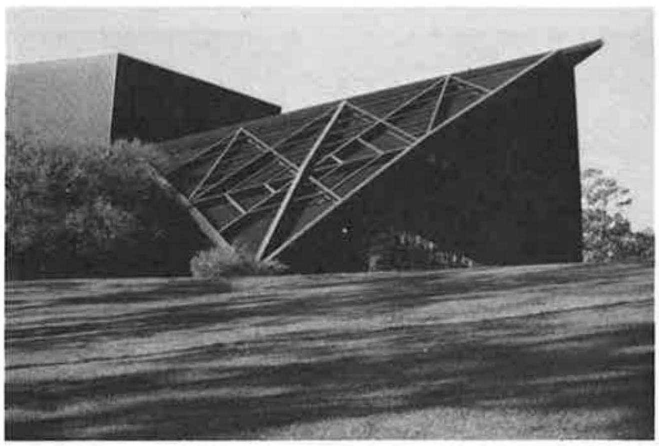

FIGURE 9 Weathering steel structure with corrugated metal roof.

it corroded through. The entire roof of this building has been replaced, but this failure could have been predicted before construction. Corrugated roofing, similar to the one shown in Figures 9, 10, and 11, was one of the earliest tests for precursors of weathering steels *(8)*. Recommendations were available in the 1960s indicating that painting or sealants would be required at loose joints between structural steel members *(6)*. Corrosion products from the roof shown in these figures have negligible salt levels.

Figure 12 shows corrosion of permanent-form decking underneath the floor slab of a parking garage. The corrosion at this location has progressed from the inside out. The corrosion is associated with long-term wetting of the top (adjacent to the concrete) surface of the corrugated weathering steel. The metal in the center of the photograph shows a strain gage used to measure movement of the cracked concrete above the corrugated metal. The crack allowed the wetting that caused the corrosion. Voids in concrete were associated with corrosion at other locations. The building shown in Figure 12 is located in a seaport city. The boldly exposed, and well-drained, portions of the building do not have excessive corrosion despite exposure to a marine-atmosphere environment *(14)*.

The problems shown in Figures 8 to 12 are typical of those noted on weathering steel buildings in the United States. A

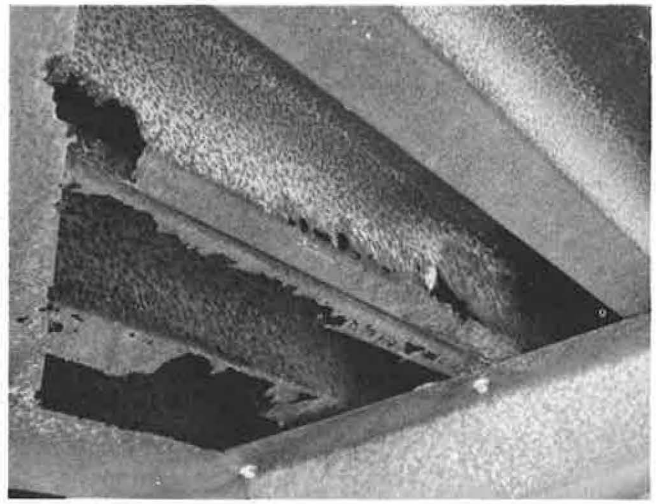

FIGURE 10 Corrosion of the corrugated metal roof shown in Figure 9.

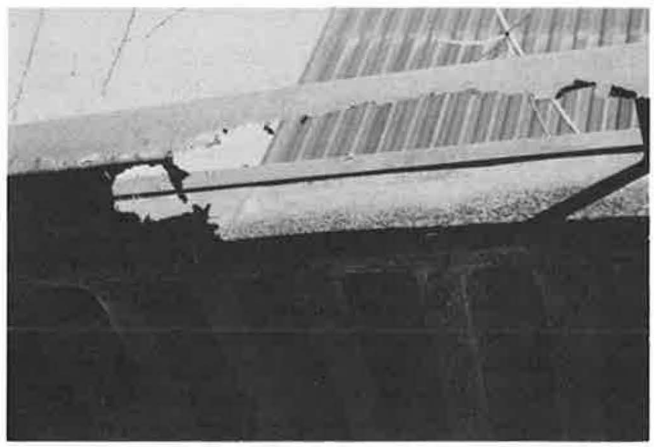

FIGURE 11 Corrosion of horizontal gutter on the same building shown in Figures 9 and 10.

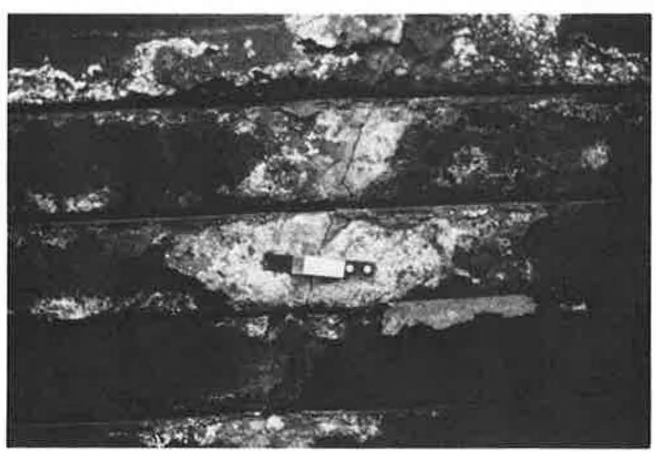

FIGURE 12 Corrosion of permanent-form decking underneath the floor slab of a parking garage.

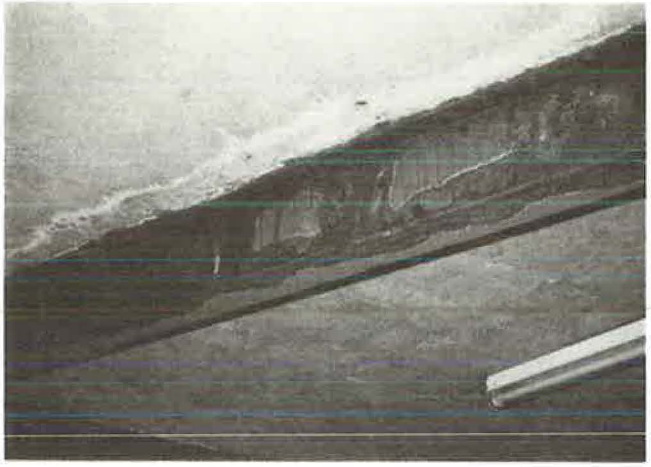

FIGURE 13 Salt stains and corrosion patterns on a weathering steel parking garage in Cleveland, Ohio.

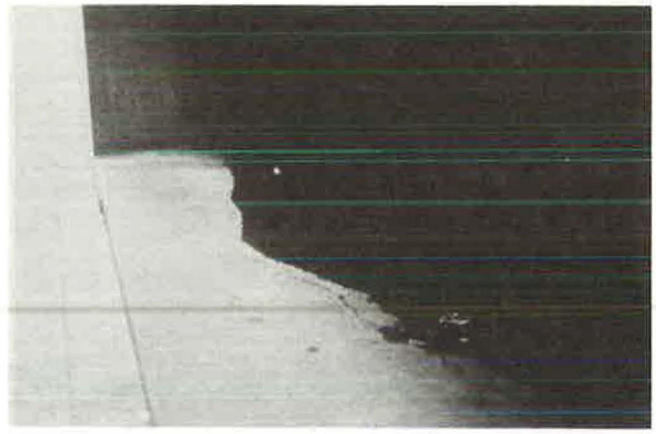

FIGURE 15 Standing water on flat floor of the statue shown in Figure 14.

recent report shows similar problems on European buildings *(15)*. Most of this type of corrosion on buildings is due to crevices and inadequate drainage. Salts are not involved on most of these buildings, although they can have a major effect in parking garages (Figure 13).

Figure 14 shows a well known statue in front of a public building in downtown Chicago. This early photograph of the statue shows light-colored rust and streaking that develops on many new weathering steel structures. The statue in question is located near heavy deicing salt applications. Despite the presence of these salts, most of the structure has developed a protective patina and is safeguarded against excessive corrosion. The only portion of the statue where nonprotective thick scales have formed is on the flat floor of the hollow statue. Figure 15 shows standing water on the floor of the statue. Corrosion products as thick as 1 to 2 cm can be removed from this location. These nonprotective scales are due to the poor drainage at this location and are not the result of deicing salts.

In the early 1970s several steel companies promoted marine grades of weathering steels. At least one company still used marine atmospheric exposures in its promotional literature in the 1980s. Many applications of these marine grades were unsuccessful, and most steel companies no longer promote weathering steels for marine applications. Figure 16 shows sheet piling alongside a tidal creek in Annapolis, Maryland. Most of the sheet piling has not corroded through, but there are perforations of the steel in many areas. Corrosion from the (continuously wetted) back side of the steel has caused these perforations. Similar corrosion patterns can be noted on sheet piling in other marine locations such as Port Canaveral, Florida, and Galveston, Texas. Salts from the marine environment could be expected to cause corrosion in these locations, and doubtless they do contribute to the corrosion that does occur, but most of the corrosion is caused by the lack of drying. Sheet piling along the Detroit River (freshwater) in Michigan shows the same corrosion patterns as the marine locations in Maryland, Florida, and Texas.

FIGURE 14 Weathering steel statue located in downtown Chicago.

FIGURE 16 Corroded sheet piling along a tidal creek in Annapolis, Maryland.

CONCLUSIONS

The use of weathering steel for highway construction will remain controversial. The most common cause of poor performance of weathering steels is inadequate drainage. Deicing salts and marine environments play a secondary role. Evidence that points to poor design as a contributor to problems with weathering steel structure performance can be gained by examining buildings and other structures that are not exposed to marine environments, or deicing salts and similar chemicals. Further support can be added by the examination of protected portions of the same structure—locations that have remained dry or, more commonly, have been exposed to alternate wetting and drying.

REFERENCES

1. B. Paul. Weathering Steel Prompts a Big Debate. *Wall Street Journal*, Dec. 10, 1982, p. 33.
2. P. Albrecht and A. Naeemi. *NCHRP Report 272: The Performance of Weathering Steel in Bridges*, TRB, National Research Council, Washington, D.C., July 1984.
3. *Performance of Weathering Steel in Highway Bridges*. American Iron and Steel Institute, Washington, D.C., Aug. 1982.
4. *Design Division Informational Memorandum #263-B*. Michigan Department of Transportation, Lansing, June 5, 1979.
5. R. Madison. Unpainted Steel for Permanent Structures. *Civil Engineering*, Feb. 1966, pp. 68–72.
6. S. Coburn. Rust Can Be Beautiful. *Metal Progress*, Aug. 1965, p. 135.
7. D. Manning, K. Bassi, and T. Kingsland. *Accelerated Corrosion in Weathering Steel Bridges*. Ontario Ministry of Transportation and Communication Report ME-84-03, Downsview, Ontario, Canada, Dec. 1984.
8. S. Coburn. Atmospheric Corrosion. *Metals Handbook*, Volume 1, American Society for Metals, Metals Park, Ohio, 1978, pp. 717-723.
9. J. Keiser, C. Brown, and R. Heidersbach. Use of Raman Spectroscopy in Iron Corrosion Studies. *American Laboratory*, Vol. 14, No. 4, April 1982, pp. 17–25.
10. A. Raman, A. Razvan, B. Kuban, K. Clement, and W. Graves. Characteristics of the Rust from Weathering Steels in Louisiana Bridge Spans. *Corrosion*, Aug. 1986, Vol. 42, No. 8, pp. 447-455.
11. W. Moore. Houston Amphitheater Roof. *Civil Engineering*, Nov. 1969, front cover and pp. 70–72.
12. D. Manning. Accelerated Corrosion in Weathering Steel Bridges. *Proceedings of Canadian Structural Engineering Conference, 1984*, Canadian Steel Construction Council, Willowdale, Ontario Canada, 1984.
13. J. Baron. Out of the Corrosion and Into the Rust. *Painting and Wallcovering Contractor*, Vol. 45, No. 11, Nov. 1983, p. 15.
14. R. Heidersbach. Corrosion. *Attorney's Guide to Engineering*, Chapter 3 (I. Kuperstein and N. Salters eds.), Matthew-Bender, New York, 1986.
15. J. Gullman, D. Knotkova, V. Kucera, P. Swartling, and J. Vlickova. *Weathering Steels in Building*, Bulletin No. 94, Swedish Corrosion Institute, Stockholm, Sweden, 1985.

DISCUSSION

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Heidersbach concludes that the major cause of corrosion damage to weathering steel is poor drainage. I concur that poor drainage caused by inadequate design and application is the major cause of corrosion damage. Several examples cited in the paper as failures of weathering steel are, in fact, illustrations of the above conclusion. I object to Dr. Heidersbach citing these examples as weathering steel "failures" without explaining that the problems were, in fact, caused by defective design or application, or both, by the architect or contractor involved. Poor drainage resulting from poor detailing or lack of maintenance resulted in the poor performance of, for example, the expansion joint on the New Jersey Turnpike (Figure 3) or the Picasso statue (Figure 14). Experience indicates that cleaning is the best maintenance technique for all types of steel structures.

Heidersbach suggests that the necessary precautions and limitations in the use of bare weathering steels are "not well known in the construction industry," as opposed to the metallurgical community. On the contrary, weathering steel producers regularly distribute technical information to the design community through handbooks *(1)*, product literature *(2)*, technical papers *(3)*, Sweet's Architectural File, and slide lectures and personal contact by regional engineers. Although some may not have taken advantage of this information, the majority of those in the construction community are, or should be, aware of the necessary precautions and limitations in the use of these steels. The metallurgical community as well as the producers of weathering steel products having published and provided a myriad of documents describing the characteristics of the products and the care needed in their use, it behooves any architect and contractor using them to make use of this literature and heed the warnings and advice contained therein.

REFERENCES

1. *Exposed Steel for Achitectural Design*. United States Steel Corporation (now USX Corporation), Pittsburgh, Pa., 1965 (updated yearly).
2. *Bethlehem Mayari R Weathering Steel*. Bethlehem Steel, Bethlehem, Pa., Oct. 1967.
3. *Performance of Weathering Steel in Highway Bridges*. Task Group on Weathering Steel Bridges, American Iron and Steel Institute, Washington, D.C., 1982.

AUTHOR'S CLOSURE

I welcome the comments by Almand and will try to address them in the order presented.

I find no reference to "weathering steel failures" in the manuscript. All "failures" or instances of excessive corrosion are due to misapplication of the material. While detailed literature is available and is cited as references in the manuscript, most architects and structural engineers have only limited knowledge of this literature. The manuscript assesses no blame, and I still maintain that the limitations are not well known by construction industry designers and specifiers. Whether they "should be" aware of this information is open to question. The purpose of this paper was to make the necessary information more accessible to designers and decision makers.

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