A Low-Cost Maintenance-Free Structural Steel for Highway Applications

S. K. COBURN
Applied Research Laboratory, United States Steel Corporation, Monroeville, Pennsylvania

Highway engineers and landscape architects have indicated a need for a structural material that is low in initial cost and requires a minimum expenditure of money and labor for maintenance. Such a product is required for use in roadside rest area buildings, highway guardrails, median barriers, signposts and structures, lighting standards, snow fences, bridges, and utility poles and towers. There is also a desire in some instances to reduce the amount of light-reflective materials employed in highway structures and thus minimize distraction from the natural scenery. The use of unpainted high-strength low-alloy steel containing certain alloying elements to improve atmospheric corrosion resistance appears to fulfill this need. The superior mechanical properties and enhanced resistance to atmospheric corrosion of one of these steels in various environments are described. Examples are given illustrating the current use of this steel in such applications as transmission towers, large buildings, light standards, and bridges.

•THE GROWING body of literature describing the numerous studies conducted by municipal, state, and Federal highway agencies concerning the various facets of highway construction, operation, and maintenance attests to the engineering complexity of this 20th century phenomenon—the highway.

Over the years a wide variety of materials has been employed by highway and bridge engineers and by landscape architects to implement their design concepts. Such terms as strength, durability, resistance to impact, resistance to atmospheric corrosion, cost of maintenance, and esthetic appeal are constantly being used to describe the performance of the materials utilized in highway construction practice. Often materials that have performed effectively in another industry may be transferred to a highway application with excellent chances for success. But the best test for evaluating a construction material is service performance over extended periods of time.

When a corrosion engineer surveys the highway research literature, he encounters comments and observations such as the following:

1. The increasing use of highways to serve as rights-of-way for communication and power line poles and towers is a fact that must be accepted as an economic approach to lower operating costs and rates, in spite of the fact that the presence of such installations is not always esthetically pleasing (1, 2);
2. The most objectionable esthetic feature of many new urban freeways is the excessive amount of shiny metal—guardrails, fences, railings, lampposts, sign standards, etc. (3);
3. Roadside rest areas should contain buildings and structures that require little or no maintenance and employ brick, tile, or stone so as to be of a permanent nature (4); and

---

Paper sponsored by Committee on Metals in Highway Structures.

TABLE 1

COMPOSITION RANGES AND TYPICAL COMPOSITION FOR HIGH-STRENGTH LOW-ALLOY STEEL[a]

Element	Composition (%)	
	Range	Typical
C	0.12 max.	0.09
Mn	0.20-0.50	0.38
P	0.07-0.15	0.09
S	0.05 max	0.033
Si	0.25-0.75	0.48
Cu	0.25-0.55	0.41
Cr	0.30-1.25	0.84
Ni	0.65 max.	0.28

[a] COR-TEN, U.S. Steel Corp.; alloy of Cr, Si, Cu, Ni, and P.

4. A typical urban area in Iowa contains 52 signs and 43 signposts per mile, and two-man paint crews waste from 35 to 50 percent of their time waiting for the posts to be repaired before they can paint them (5).

It is evident from such comments that highway engineers are actively seeking alternative materials of construction that are low in initial cost, require little or no maintenance, involve a minimum expenditure for labor, and are esthetically pleasing for the specific application. A final requirement is that a structural material, in addition to fulfilling economic and engineering requirements, should alter the natural scenery as little as possible.

These are an imposing set of requirements for any single structural material; however, a specific type of steel produced in a variety of shapes and forms is available to meet these needs. This product is known as a high-strength low-alloy steel and is characterized in mechanical properties by a minimum yield point of 50,000 psi in accordance with Specification A 242 of the American Society for Testing and Materials (ASTM). (ASTM A 242 describes the properties for structural shapes and bars, for welded, riveted, or bolted construction; ASTM A 374 and A 375, respectively, deal with cold-rolled and hot-rolled steel sheets and strips in cut lengths and coils.) The particular high-strength low-alloy steel discussed herein (COR-TEN, U.S. Steel Corp.) meets the requirements of the ASTM A 242 specification in thicknesses up to and including ½ in., provides five to eight times the resistance to atmospheric corrosion that can be obtained with structural carbon steel with low residual copper content, and can be used in the unpainted condition for many boldly exposed applications. The applications discussed hereafter specifically cover the use of unpainted high-strength low-alloy steel. Because ASTM A 242 does not specify the alloy elements required to obtain enhanced resistance to atmospheric corrosion, a structural design engineer should inform his supplier of the intended usage and indicate the need for a steel with a chemical composition that includes the elements Cr, Si, Cu, Ni, and P in the composition range shown in Table 1. It should be recognized that although this paper is devoted to a discussion of a specific steel composition, active research programs are being pursued towards the development of other steels with enhanced atmospheric corrosion resistance, equivalent mechanical properties and weldability. Thus, it is expected that in the near future additional steel compositions will be available for use in the highway applications discussed herein.

CHARACTERISTICS OF HIGH-STRENGTH LOW-ALLOY STEEL

It is evident from the composition of the high-strength low-alloy steel given in Table 1 that the elements Cr, Si, Cu, Ni, and P are present in larger than just trace quantities. These elements exert a significant influence on the corrosion resistance and mechanical properties of this steel. The mechanical and engineering properties of this steel are described in Table 2. For comparison, Table 3 contains a listing of the properties of ASTM A 36 structural carbon steel.

Atmospheric Corrosion Resistance

Before discussing the unique properties of this high-strength low-alloy steel, it would be well to consider briefly why and how steel rusts in the atmosphere. Iron

TABLE 2

MECHANICAL PROPERTIES (MINIMUM) OF HIGH-STRENGTH LOW-ALLOY STEEL

Steel Thickness (in.)	Yield Point (psi)	Tensile Strength (psi)	Elongation (%)	
			In 8 In.[a]	In 2 In.
≤½	50,000	70,000	19	22
>½-1½[b]	47,000	67,000	19	–
>1½-3	43,000	63,000	16	24

[a]This steel can be joined by riveting or bolting in all thickness and can be welded in thicknesses up to and including ½ in.

[b]0.180 in. and heavier.

TABLE 3

COMPARATIVE PROPERTIES AND ENGINEERING DATA

Mechanical Properties (at ≤ ½ in. thick)	High-Strength Low-Alloy Steel	Structural Carbon Steel (ASTM A 36)
Yield point, min, psi	50,000	36,000
Tensile strength, psi	70,000 min	58/80,000
Elongation in 2 in., min, percent	22	23
Elongation in 8 in., min, percent, 0.180 in. and heavier	18	20
Cold bend	180° D = 1T	180° D = 1/2T
Resistance to atmospheric corrosion (comparative)	4 to 6	1 (or 2 with copper 0.20% min)
Compressive yield point, psi	Tensile Y. P.	Tensile Y. P.
Shearing strength, psi	0.70 T. S.	0.70 T. S.
Modulus of elasticity, psi	28/30,000,000	28/30,000,000
Charpy impact, keyhole notch (as rolled, room temperature, average), ft-lb	40	25
Coefficient of expansion per degree F, -50 to 150 F	0.0000065	0.0000065

and other metals oxidize because they have a considerable affinity for oxygen. This strong potential for uniting with oxygen is related to the large amounts of energy used to extract the iron from its ore. To prevent oxidation, which occurs only in the presence of moisture on the surface, a barrier must be inserted between the steel and the atmosphere. With stainless steel a thin, transparent, almost impervious oxide film forms naturally and is extremely effective in preventing corrosion. Oxide films also form on carbon steel; however, because they tend to be voluminous and porous, they are usually incapable of sealing the surface effectively. Therefore, carbon steel tends to oxidize continuously.

It has been established that the corrosion process that occurs on steel in contact with the necessary film of moisture is an electrochemical one similar to the action in a battery. At any given instant, some areas are corroding and are called anodic sites; areas that are not corroding serve as cathodic sites. Small electrical currents flow between the anodic and cathodic sites. Initiation of these so-called corrosion currents is stimulated by the presence of small amounts of dissolved salts, alkalis, or acids that are almost always present in the atmosphere and which deposit on the metal surface.

The pioneering work of Buck, (7) and the early publications and interpretations of the results of ASTM tests conducted from 1916 through 1951 (8) have demonstrated that the introduction of small amounts of copper into carbon steel increases its atmospheric corrosion resistance appreciably (9). The ASTM tests show that a minimum of 0.20 percent copper added to carbon steel doubles its atmospheric corrosion resistance. The results of numerous atmospheric corrosion tests conducted during the past 30 yr confirm these observations and also show that the high-strength low-alloy steel under discussion is at least four and often as much as eight times as resistant to corrosion as carbon steel.

Manner of Conducting Exposure Tests

The standard ASTM testing method for obtaining corrosion data is illustrated in Figure 1. Test specimens of various compositions are exposed on a rack inclined 30 deg to the horizontal and facing south. The specimens are cleaned and weighed before exposure, and individual specimens are removed at scheduled intervals for evaluation and then discarded. The reduction in thickness is calculated from the loss in weight. A time-corrosion curve is established from data developed during several exposure periods. The slope of this curve in the linear portion indicates the corrosion rate.

Results of Exposure Tests

Time-corrosion curves describing the performance in an industrial atmosphere of the high-strength low-alloy steel in comparison with a copper-bearing steel and a carbon steel are shown in Figure 2. For these curves, the calculated reduction in thickness in mils of test specimens is plotted against the time of exposure in years. It is evident that the high-strength low-alloy steel is far more resistant to corrosion in an industrial atmosphere than are either the copper-bearing steel or the carbon steel. The narrowness of the bands shows that the thickness of the respective test specimens did not influence the corrosion rates and indicates that corrosion is a surface phenomenon. Similar results illustrating the superiority of the high-strength low-alloy steel over carbon steel in a semi-rural atmosphere are shown in Figure 3.

Figure 1. Typical arrangement of test specimens on exposure racks, 800-ft lot, Kure Beach, N.C.

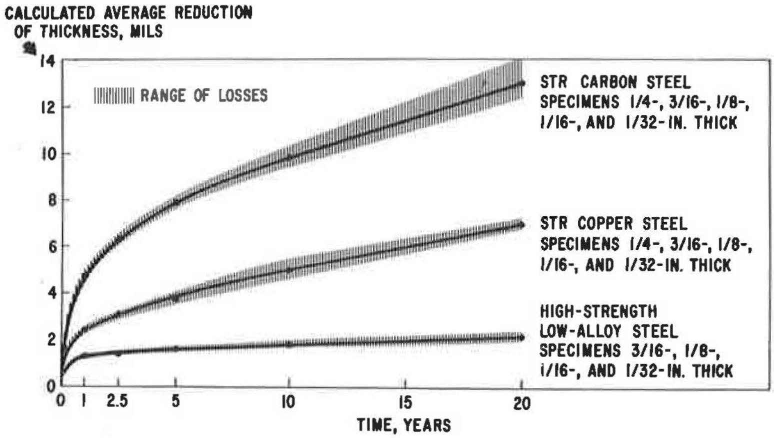


Figure 2. Comparative corrosion of steels (1-ft square specimens) in industrial atmosphere, Kearny, N.J.

Figures 2 and 3 also show that approximately 80 percent of the corrosion occurring on the high-strength low-alloy steel in both the industrial and the semi-rural atmospheres occurs within the first 2 to 3 yr of exposure. This amounts to a reduction of about 1.5 mils in metal thickness. The corrosion that occurs in the next 20 yr reduces the thickness by only about another 0.5 mil. Thus, it is clear that the structural integrity of the high-strength low-alloy steel is not endangered by corrosion when it is properly used in the boldly exposed condition.

Figure 4 illustrates the comparative corrosion losses for specimens of carbon steel and the high-strength low-alloy steel at 80 and 800 ft from the Atlantic Ocean at Kure Beach, N.C. Although the performance of the high-strength low-alloy steel at the 80-ft lot is superior to that of carbon steel, the corrosion rate is so high that its use in the unpainted condition would be inadvisable in severely corrosive marine atmospheres. Specimens located 800 ft from the ocean corrode at a considerably lower rate, and the superior performance of the high-strength low-alloy steel over carbon steel is again evident. Applications close to seawater may warrant consideration of galvanizing or painting the high-strength low-alloy steel.

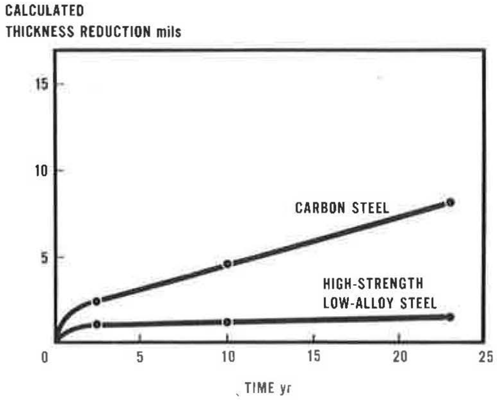


Figure 3. Comparative corrosion of steels in semirural atmosphere.

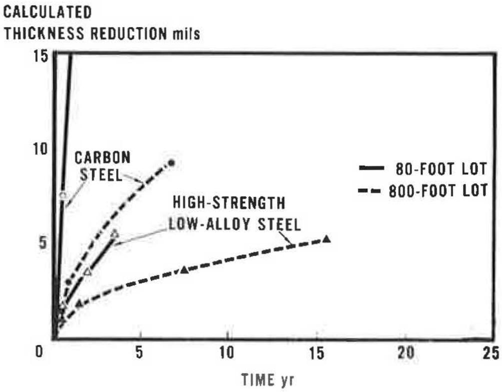


Figure 4. Comparative corrosion of steels in marine atmosphere, Kure Beach, N.C.

SURFACE PROTECTION

Formation of Protective Oxide Film

The satisfactory atmospheric corrosion resistance of the unpainted high-strength low-alloy steel is dependent on the chemical composition containing the unique combination of alloying elements necessary for the development of the thin, tightly adherent, protective oxide film. The interaction between these elements and various environmental constituents has not been completely established; however, several factors are apparent. The kind and amount of contamination in the atmosphere are significant. Other critical factors are sunlight, rain, and dew. As mentioned previously, moisture must be present for corrosion to occur. The drying effect of sunlight assists in the formation of the protective oxide film from the corrosion product. Rain is helpful in washing away water-soluble iron compounds that form during the corrosion process. Dew is considered to be especially important because it remains on the steel surface for a substantial period during the night and absorbs atmospheric pollutants that can assist in the formation of the oxide film.

The extent of corrosion of steel in a particular locality can be influenced by the type of fuel being burned and the kind of combustion products released to the atmosphere. Although many industrial effluents are responsible for corrosive attack, these same contaminants, particularly the sulfur-containing compounds, assist in the formation of the protective oxide film on the surface of the high-strength low-alloy steel.

Characteristics of Rust Film

In the as-rolled condition, the appearance of the high-strength low-alloy steel surface is very similar to that of carbon steel. The color and texture of the rust film that forms on the high-strength low-alloy steel, however, differs markedly from that which forms on carbon steel. Figure 5 shows the appearance of the rust film on steels exposed in an industrial atmosphere for 15 yr. The rust film that forms on carbon steel is voluminous and reddish brown in color. That which forms on the high-strength low-alloy steel is very thin, no more than several mils thick. The color of this thin rust film changes progressively, depending on the time of exposure and the kind and amount of atmospheric contamination present, and ranges between a dark reddish brown and a warm purple gray.

Furthermore, the rust film on the high-strength low-alloy steel, unlike that on carbon steel, is not scaly and loose but fine grained and tightly adherent. Whereas large patches of rust fall from a bare carbon steel structure as it weathers, the initial rust film on the high-strength low-alloy steel slowly dusts away through the erosive action of wind and rain and after a time the formation of loose rust virtually ceases. In rural and semi-rural atmospheres, where the amount of air pollution is relatively

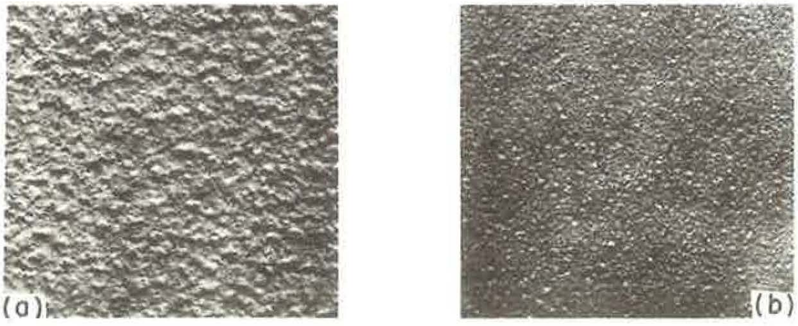


Figure 5. Appearance of rust after 15 yr in industrial atmosphere: (a) carbon steel, and (b) high-strength low-alloy steel.

low, the change in color of the rust film will be extended over a relatively longer period of time. At any one time, the color of the rust film will be essentially uniform and the change in color will be almost imperceptible.

Performance of High-Strength Low-Alloy Steel in Different Locations

Another series of exposure tests has been conducted in widely separated parts of the country to determine the effect of surface condition of the test specimens at the time of exposure. Welded specimens of the high-strength low-alloy steel and of carbon steel were exposed in each of six metropolitan areas and one seacoast location. These sites were selected on the basis of conditions peculiar to their location. San Francisco's nightly fog, Birmingham's lack of prevailing wind, and Newark's chemical industry are typical of the variety of local conditions sought for this investigation. For each location, one pair of specimens were sandblasted before exposure, a second pair were acid-pickled, and a third pair had the mill scale intact. The carbon steel specimens were welded with carbon steel electrodes; the high-strength low-alloy steel specimens were welded with a 2 percent nickel electrode.

The results after 2 yr of exposure indicate that with all three initial surface conditions, the high-strength low-alloy steel performs well in each of the test areas: in the Newark-New York area; the Gary and Chicago areas; in Birmingham, Washington, San Francisco, and Seattle; and at the marine site, 800 ft from the ocean, at Kure Beach, N. C. In each location, a dark tightly adherent oxide film formed. Furthermore, regardless of the surface condition, the characteristic homogeneous-appearing rust film formed during the first 2 yr of exposure. Figure 6 shows the respective specimens exposed on a test rack in Chicago. The darker appearing specimens on the right are of high-strength low-alloy steel. Although in all cases the oxide film formed on the specimens from which mill scale was not removed, mill scale should be removed by pickling or blasting to obtain optimum appearance during the initial exposure period.

Effect of Sulfur in Atmosphere

As indicated earlier, the protective rust film forms most readily on the high-strength low-alloy steel when it is exposed in localities where industrial and home-heating exhaust gases from the combustion of coal and oil contribute sulfur compounds to the atmosphere. However, sulfur compounds are also present in the rural areas of the country as a consequence of the decomposition of field crops, the burning of diesel fuel in farm equipment, and the general movement of weather. Because of the widespread interest in sulfur as a crop nutrient, soil and rainwater have been analyzed for sulfur in about 20 states. Some of the more recent work has been summarized in a United States Department of Agriculture technical bulletin (10). Table 4 gives a few of the results reported. It is evident from these data that sufficient sulfur is widely available in the atmosphere to promote the formation on the steel of a tightly adherent, protective oxide film that gradually assumes a reddish to gray-brown appearance.

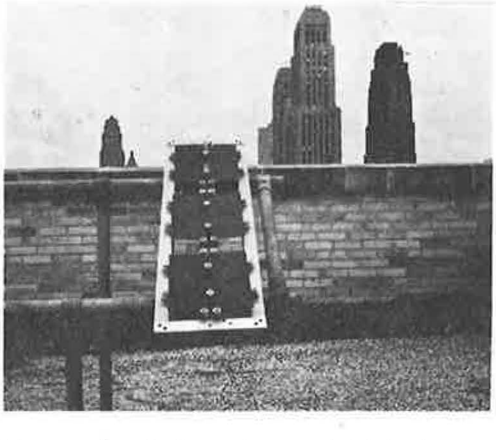


Figure 6. Carbon steel and high-strength low-alloy steel specimens on roof, Chicago, Ill.

Staining

During the formation of the protective oxide film, a small amount of water-soluble corrosion products will form. These will be washed down the members of a structure by rain or other sources of moisture and will cause staining on concrete

TABLE 4

SULFUR COLLECTED IN RAINWATER, DECEMBER 1952 TO NOVEMBER 1955

State	No. Locations	Avg. Ann. Accretion (lb/acre)
Ala.	2	6
Fla.	6	2-7
Ga.	5	4-8
Ky.	6	8-14
Miss.	7	3-7
N. C.	16	4-14
Tex.	5	5-11
Va.	19	12-31

footings, galvanized hardware, and unglazed porous brick.

If the rust-bearing water flows over concrete surfaces, the alkali in the concrete causes precipitation of brightly colored iron salts which can adhere and permanently discolor the footing. If this discoloration is objectionable, it can be minimized by designing the footing so that water will not stagnate but will drain away. Another approach is to apply a dark-colored paint with a glossy finish that will prevent stains from being easily seen. The concrete may also be coated with a silicone-type preparation that will prevent the iron-bearing water from reacting with the alkali in the concrete. If the rust-bearing water should contact galvanized hardware, the alkaline surface will cause iron salts to precipitate on the surface of the zinc in the same manner. These superficial deposits, however, will not in any way impair the effectiveness of the protective zinc coating.

Safety

Safety must be an important consideration when new equipment and new materials of construction are proposed. Because of the granular texture of the high-strength low-alloy steel surface, linemen and other workers are afforded a more positive footing on both wet and dry surfaces.

Because of the absence of any coating, metal-to-metal contact can be obtained in bolted connections; thus, the possibility that the connections will loosen under vibration is minimized.

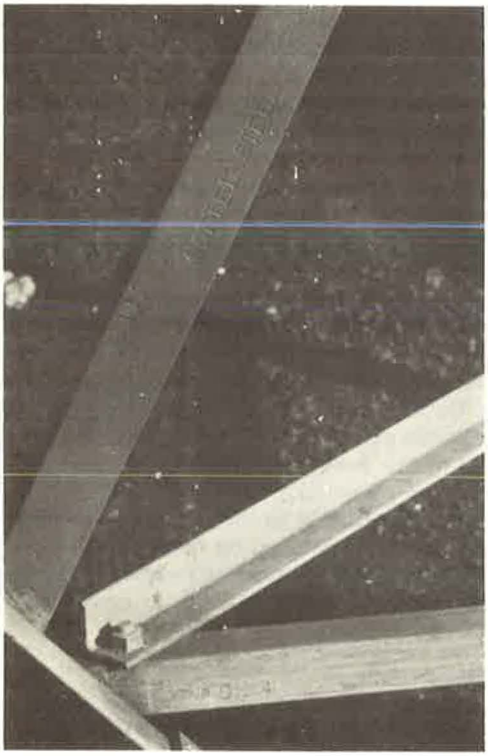


Figure 7. High-strength low-alloy steel angle on galvanized steel transmission tower after 15 yr of exposure, Gary Steel Works.

SOME APPLICATIONS FOR UNPAINTED HIGH-STRENGTH LOW-ALLOY STEELS

Transmission Towers

Although the high-strength low-alloy steel has been available since 1932, utility engineers have recognized its potentialities only in recent years. In 1948, an unpainted angle member (Fig. 7) was installed in a galvanized carbon-steel tower at the Gary Steel Works of the U. S. Steel Corp. Periodic thickness measurements have been made and to date no significant changes have occurred. It might be expected that severe corrosion would first occur in the bolted connection, so the angle was removed and examined. There was almost no indication of attack in the area of contact between the unpainted and the galvanized members. The zinc surface was still bright and shiny, and the bare steel had only a superficial coating of rust.

Since that time, several other installations of this steel, in the unpainted condi-

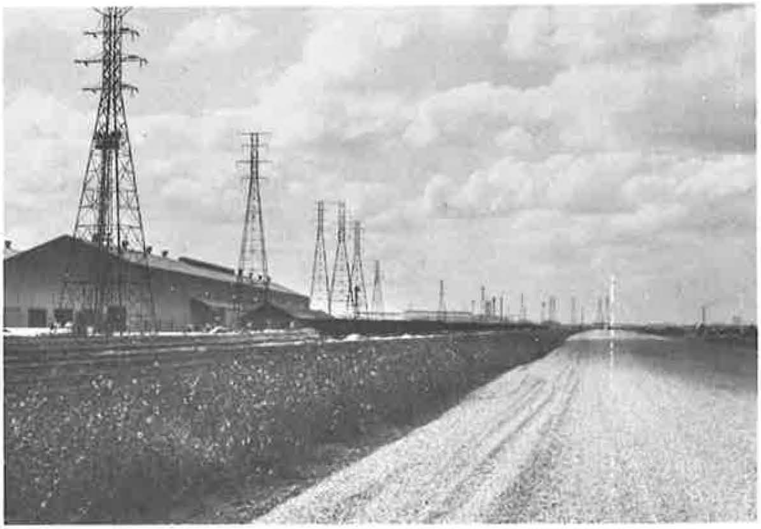


Figure 8. High-strength low-alloy steel 69-kv transmission towers, Gary Steel Works.

tion, have been made and are under programmed surveillance for future reporting. A brief description of some of the more interesting of these is given in the following.

Figure 8 shows a few of the seventeen 69-kilovolt (kv) double-circuit transmission towers located on the south shore of Lake Michigan within the Gary Sheet and Tin Works of the U.S. Steel Corp. The towers were erected early in 1960. Atmospheric conditions at this location—frequent lake breezes and mist, sunshine, rain, and proximity to an industrial plant—are optimum for the rapid formation of the protective oxide film on the unpainted steel. Recent examinations of these towers have shown that the rust film is tightly adherent to the base metal and has assumed a dark brown color.

Figure 9. Appearance of high-strength low-alloy steel in Project EHV after 2 yr near Pittsfield, Mass.

Transmission tower No. 18 in General Electric Company's Project EHV (11) was erected of high-strength low-alloy steel in a semi-rural area near Pittsfield, Mass., in 1960. Figure 9 shows the surface after 2 yr of exposure. The texture of the rust is still slightly granular but is generally tightly adherent to the base metal. The structure has assumed a deep brown color.

At a new highway crossing in a rural area near Brookville, Pa., the West Penn Power Co. in January 1962 erected two 138-kv H-frame transmission towers. Figure 10 shows one of these structures. Eight months after erection, all surfaces, except the base of the tower legs, had developed a generally homogeneous reddish-brown protective oxide film. At the base of the tower legs, two light-colored streamers developed as a result of the nightly formation and condensation of low-level ground fog. Moisture condensed on the lower braces and drained down the

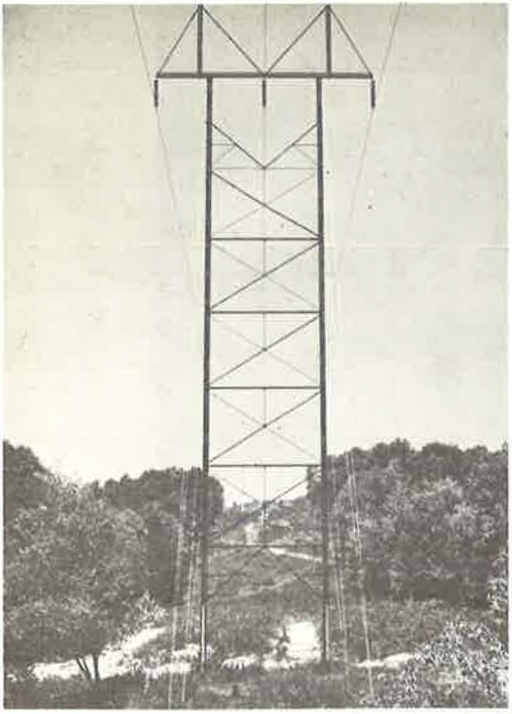


Figure 10. High-strength low-alloy steel transmission towers after 8 mo near Brookville, Pa.

tower legs, thus maintaining a wet condition that caused development of the color in the wash area to lag behind that in the balance of the tower. If appearance is an important factor, the water flow on this type of structure can be diverted by designing to facilitate drainage.

Figure 11 shows a high-strength low-alloy steel wide-flange beam (6 by 6 in., 15.5 lb/lin ft) used as a crossarm on wooden poles in a 115-kv transmission line. With the formation of the protective oxide, the general color of the arm tends to blend in with the color of the pressure-creosoted poles. In addition, the high-strength low-alloy steel arm is lighter and less expensive than the wooden arm it replaces, even with the cost of an additional insulator per string to make up for the insulation lost by the substitution of steel for wood. Many installations of this type have been in operation for about 6 mo.

The Virginia Electric and Power Co. of Richmond, Va., encouraged by the good performance of the aforementioned installations, is using high-strength low-alloy steel for all towers in its 350-mi 500-kv transmission line presently being erected in West Virginia and Virginia (12).

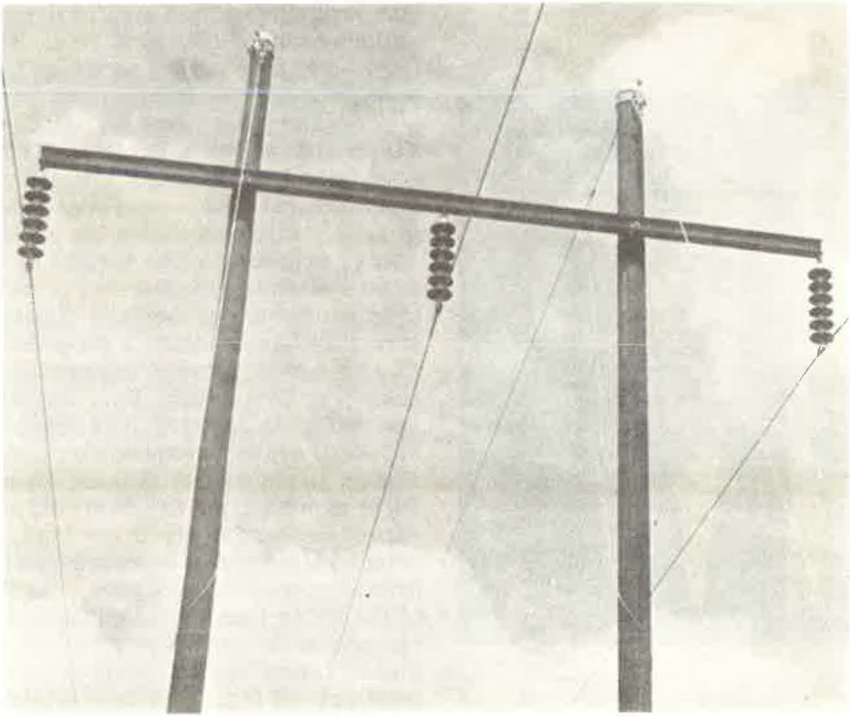


Figure 11. High-strength low-alloy steel crossarm application on creosoted poles.

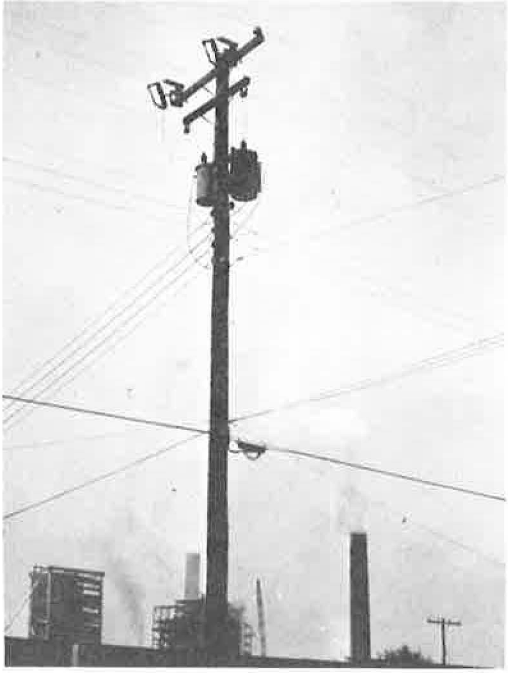


Figure 12. Effluent from smoke stack deposits on transformer tank of high-strength low-alloy steel and painted carbon steel, Georgetown, S.C.

In Georgetown, S.C., about 10 mi from the ocean and just outside a large paper mill, a 25-kva distribution transformer is incased in an unpainted high-strength low-alloy steel tank and cover. A painted carbon steel unit is mounted next to it. After 3 yr of exposure, a pleasing dark brown rust film has formed on the surface of the high-strength low-alloy steel tank and its cover. It has been the experience of the Georgetown utility company engineers that the painted carbon steel tanks require touch up maintenance at the end of 3 yr of service and complete repainting after 5 yr. When the 3-yr inspection was made in June 1964, large areas of paint were observed flaking from the carbon steel tank cover and base. The high-strength low-alloy tank was in good condition (Fig. 12). It is evident that this essentially rural area in close proximity to the paper mill actually is quite corrosive. These particular atmospheric conditions, however, effectively promote the formation of the dark tightly adherent oxide film.

Buildings

During the summer of 1962, a two-story building was erected on the campus of the University of South Dakota at Vermillion. Approximately 36 unpainted H-beam col-

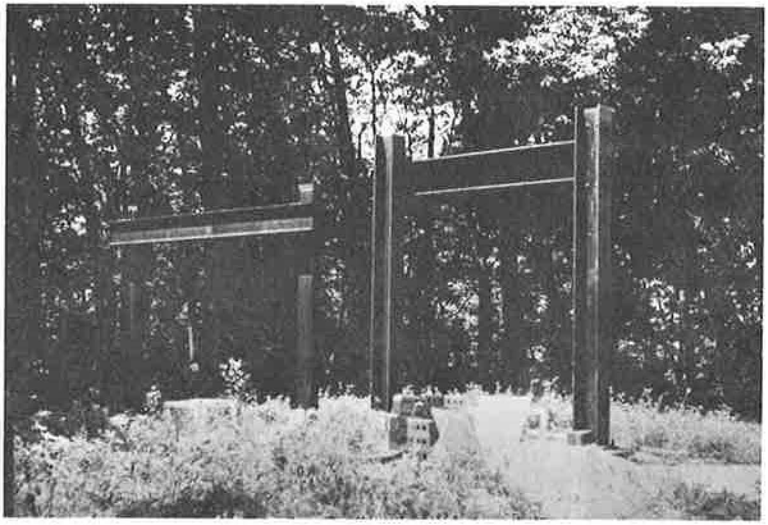


Figure 13. Mock-up of high-strength low-alloy steel in atmospheric exposure test, Moline, Ill.

umns were used as part of the exterior wall treatment. The rural location of the building will afford an excellent opportunity to observe and compare the development of the rust film on the H-beams with that on the transmission towers near Brookville, Pa.

Located on the outskirts of Moline, Ill., is one of the finest creations of Eero Saarinen Associates—the new Deere and Co. administration center. This complex includes a bridge leading to a seven-story administration building which in turn is connected with a two-story exhibition building. This group of structures represents the first instance in which unpainted high-strength low-alloy steel has been employed in the construction of bridge members and all exterior building columns, posts, beams, girders, and sun control devices. Before this steel was specified, exposure tests of the type shown in Figure 13 were made over a 2-yr period beginning in October 1958 to establish the performance of the steel in the Moline environment. Figure 14 illustrates some of the exterior treatment of the main building which is a rigid frame all-welded structure. Additional construction details have been described in reports appearing in the Architectural Record (13, 24), the Architectural Forum (14), and Time (15).

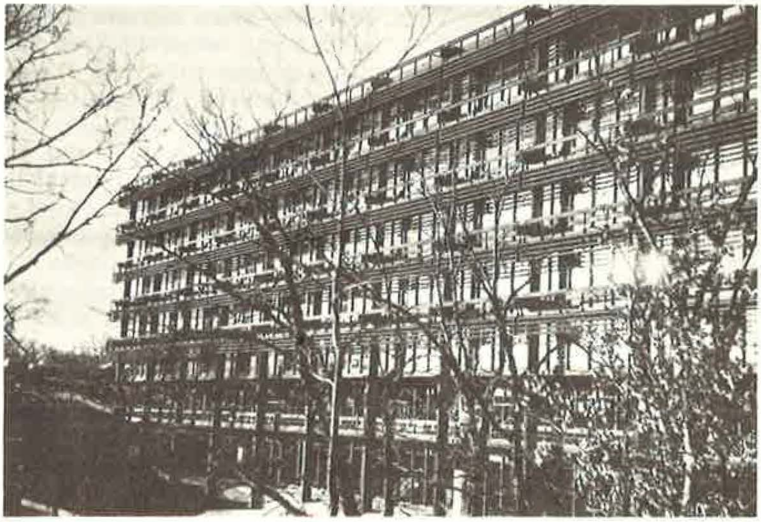


Figure 14. Exterior structural features of Deere and Company administration building, Moline, Ill.

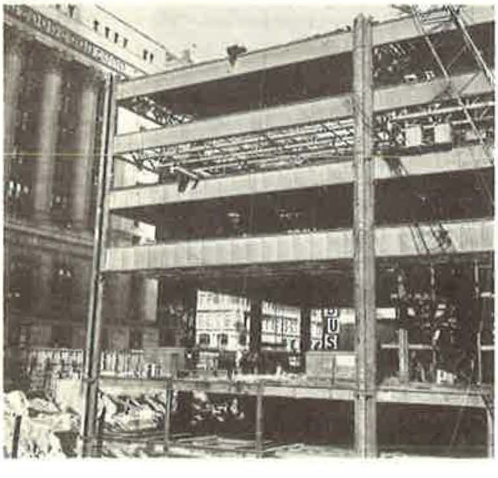


Figure 15. View of early stage of construction of Chicago Civil Courts Building.

In Chicago, where many architectural innovations have been introduced, the construction of the Chicago Civil Courts Building marks the first introduction of this steel in a multistory high-rise building in the heart of a metropolitan business center. This 680-ft, 32-story building described in the Architectural Forum is characterized by its exterior curtain walls of unpainted high-strength low-alloy steel spandrels and window sashes (16). Figure 15 is a view of an early stage of construction. Test panels of this high-strength low-alloy steel, exposed about ½ mi from the structure, indicate that the steel should reach a terminal color in about 2 to 3 yr. In each of these buildings the maintenance-free feature was a factor in the final choice of materials.

Other smaller buildings are being erected in several cities using high-strength low-alloy steel for beams, columns, and fascia. These sections are being used to serve as decorative as well as functional members.

Guardrails

Currently a number of high-strength low-alloy steel guardrail sections have been placed in service on the highways of 12 states. In some instances the material has been used as median barrier rail. The test sites are located in midwestern states as well as in states bordering the Atlantic and Pacific Oceans and the Gulf Coast. The specific exposure sites can be classified as being highly industrial, urban, and rural. Figure 16 shows the appearance some 6 mo after erection of a guardrail employed as median barrier. A rich brown oxide film has already begun to form.

The Michigan State Highway Department presently has under test a guardrail installation, similar in composition to the steel being discussed, on the approaches to one of the Interstate highways near Lansing. This test section has been exposed over two winters and has been subject to deicing salt applications and splashing from melted snow. The color and texture of the oxide film has not been affected, and the structure is continuing to exhibit its typical rustic color.

Light Standards

A high-strength low-alloy steel light standard was installed in 1960 in Monroeville, Pa., some 15 mi east of Pittsburgh. The oxide film in this semi-industrial location is developing at a satisfactory rate. One of the most impressive observations is that the light standard remains quite unobtrusive when compared with an adjacent light standard constructed of conventional materials. Figure 17 is a view of the two light standards taken during a picnic period. The high-strength low-alloy steel standard blends into the forested background, and the conventional light standard presents a contrasting

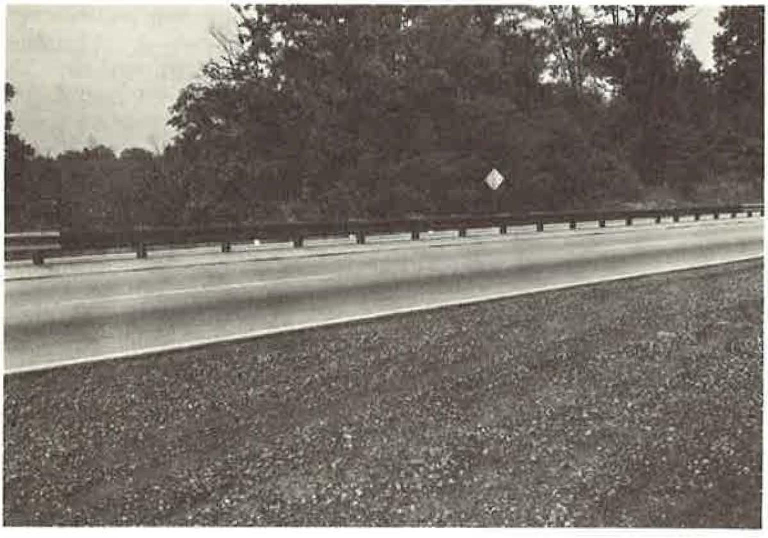


Figure 16. Experimental use of high-strength low-alloy steel in median strip.

Figure 17. High-strength low-alloy steel light standard in background.

appearance. Figure 18 is a view of a high-strength low-alloy steel light standard in a midwestern state, one of a group of 20 such test units that have been in service in this vicinity for about 2 yr.

Figure 18. High-strength low-alloy steel light standards in midwestern city.

Signposts

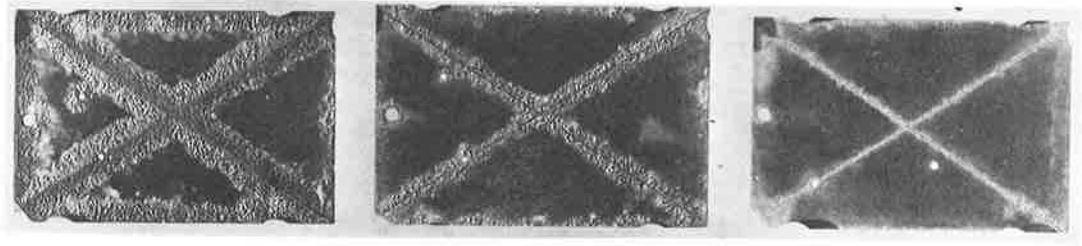
Highway signposts represent another large area where maintenance economies can be achieved through the use of corrosion-resistant high-strength low-alloy steel (5). In addition, a safety factor can be gained through its use. The results of numerous surveys designed to learn the best way of presenting information and instructions to speeding motorists have been reported in the literature. These studies included color combinations, sign configuration, sign height above ground level, letter size with respect to sign dimensions, and number of legs supporting the signs (17). It might also be desirable to conduct a study in which motorist-attention delay time in reading signs is correlated with attention-gaining colors used for signposts, legs, braces, and supporting arms. Making these structural members of maintenance-free dark-colored, high-strength low-alloy steel could contribute to highway safety and eliminate costs for painting and repainting.

Snow Fences

Snow fences represent an application where unpainted high-strength low-alloy

Figure 19. View of new snow fence design.

steel might be considered. The Roadway and Ballast Committee of the American Railway Engineering Association (18), in a report on methods of protecting roadways and track against drifting snow and sand, has evaluated the performance of perforated corrugated steel panels. This type of fence has been installed by several railroads, and comments on initial cost of materials and erection are favorable. The cost of installation and removal is comparable to those incurred with wood lath. The fence may be installed in the same manner as temporary lath fence and removed during the off-season. Because of the corrugations and perforations, stacking is simple, and the slots can be chained together to prevent pilfering. Presently, these fence panels are supplied painted and galvanized. However, they could be fabricated from high-strength low-alloy steel, in which case painting and touchup maintenance costs as well as galvanizing costs can be eliminated. Figure 19 illustrates the fence in service.

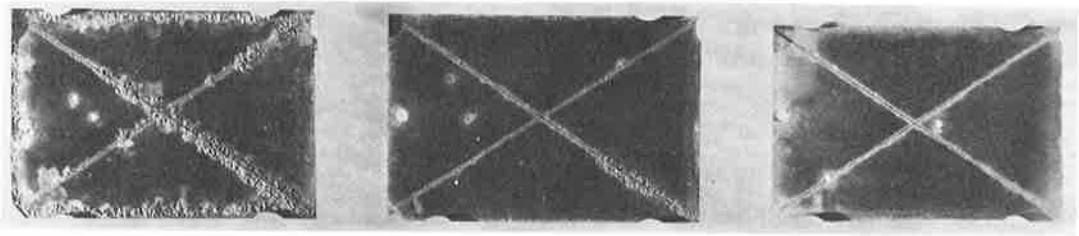


Open Hearth Iron

0.2% Cu Steel

High-Strength Low-Alloy Steel

Unprimed Surface



Open Hearth Iron

0.2% Cu Steel

High-Strength Low-Alloy Steel

Bonderite Primed Surface

Figure 20. Effect of surface treatment on painted steels after 8 mo of exposure in marine atmosphere 80 ft from Atlantic Ocean at Kure Beach, N.C.

Bridges and Overpasses

A major engineering consequence of the construction of the Interstate Highway System as well as of the expanded local highway systems is the increasing need for additional bridges and overpasses. This multiple use of space has resulted in a need for numerous medium- and short-span bridges. Together with the initial material and erection costs for such structures comes frequent paint maintenance to retain structural integrity and an esthetically pleasing appearance.

The Michigan State Highway Department has been actively seeking a steel for which painting and paint maintenance could be eliminated. Recently they selected a high-strength low-alloy steel, similar in composition to the one discussed herein, for use in the construction of a major overpass in the Detroit area. This unpainted overpass structure is now open to traffic. The performance of the steel in this application should demonstrate to bridge designers the versatility inherent in the high-strength low-alloy steels with enhanced atmospheric corrosion resistance.

The desire by engineers for steels possessing such properties as high strength and enhanced corrosion resistance will probably lead to the development of additional steels for bridge applications.

Another highway bridge built of unpainted high-strength low-alloy steel was erected in late 1964. This all-welded 3-span 110-ft long 2-lane bridge replaces an old 5-span

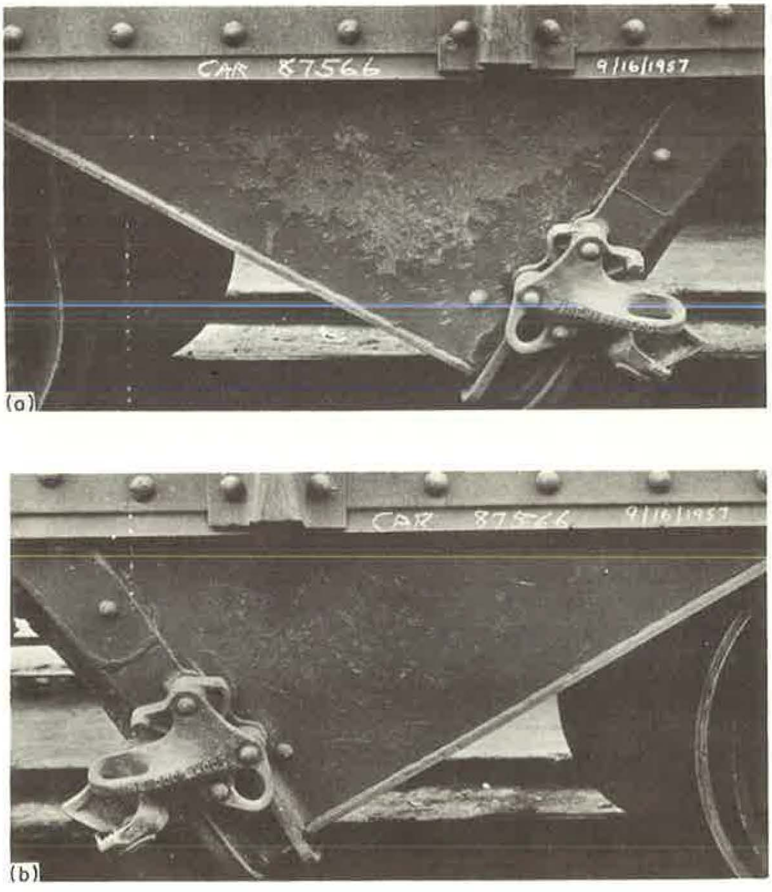


Figure 21. Appearance of painted hopper sheets: (a) copper-bearing steel, and (b) high-strength low-alloy steel.

bridge that crosses the Brush Creek in Miami County, north of Dayton, Ohio. A 4-span simple beam bridge of composite construction will be erected in 1965 as an adjunct to the New Jersey Turnpike near Morristown, N. J. This 192-ft long bridge will employ some 77 tons of a high-strength low-alloy steel in the unpainted condition. It is expected that the appearance of this bridge will be similar to that of high-strength low-alloy steel test specimens exposed in industrial areas. It should be noted, however, that these two bridges are considered experimental in the sense that if the unpainted structures are not acceptable to the bridge engineers, they may be painted.

Also, because there may be some objection to the appearance of rust stains on concrete abutments visible to the public, bridge designers employing high-strength low-alloy steels should provide for drainage of rainwater and melted snow or for painting of the affected surfaces.

Paint Performance

Hayes and Maggard of Purdue University, after evaluating the use of high-strength low-alloy steels in bridge construction, contended that the use of such steels is economically justified. They also indicated that additional economies could be achieved through a 50 percent increase in paint life (20, 21, 22). Studies by LaQue and Boylan show that the performance of an automobile paint finish on the high-strength low-alloy steel, when scribed, was very similar to that on a steel that has been bonderized before painting. Figure 20 illustrates the performance of specimens exposed 80 ft from the ocean at Kure Beach, N. C. Pretreatment of steel with phosphate compositions insures against undercutting of the paint film when it is damaged. Because the oxide film on the high-strength low-alloy steel is thin, it does not undercut paint films and thus permits the paint to perform its primary task of protecting the steel surface. Copson and Larrabee (23) also present evidence concerning the extra durability of paint on high-strength low-alloy steel. They demonstrated the performance of paint on sheets of copper-bearing steel and high-strength low-alloy steel on the sides of a railroad hopper car. After 5 yr of service, the paint on the copper-bearing steel sheets had come off relatively large areas, whereas the paint on the high-strength low-alloy steel sheets continued to give adequate protection. Figure 21 shows the performance of the paint in this service test.

SUMMARY

It is evident from the foregoing discussion concerning the mechanical and corrosion-resistant properties of the high-strength low-alloy steel that a structural material fulfilling the requirements of highway engineers and landscape architects is available and proven for use in highway applications. Because this steel develops a dark oxide film, permitting it to blend into the natural background of trees and shrubs, the landscape architect has at his disposal a material that minimizes marring of the natural scenery when used for roadside rest area buildings, signposts, etc. Engineers requiring poles, towers, and light standards that must border highways and freeways have a strong durable product that remains unobtrusive while serving a utilitarian purpose. Bridge engineers who may be seeking new means for introducing strength and economy into their bridge designs have a new construction material available on an experimental basis. Safety engineers concerned with improving sign performance also have a material that can be used selectively to solve their problems. Finally, those engineers and planners concerned with the economic phases of initial construction costs and subsequent expenditures for maintenance and appearance may choose this material because they can "build it and forget it."

REFERENCES

1. Lemly, J. H. Non-Vehicular Benefits from Utility Use of Streets and Highways. Highway Research Board Sp. Rept. 75, pp. 1-33, 1962.
2. Nelson, C. E. Economic Implications of Utility Use of Highway Locations in Utah. Highway Research Board Sp. Rept. 75, pp. 33-51, 1962.

3. Pushkarev, Boris. Highway Location as a Problem of Urban and Landscape Design. Highway Research Record No. 23, pp. 7-18, 1963.
4. Garmhausen, W. J. Roadside Rest Requirements on the Interstate Highways. In Roadside Development 1962, pp. 40-44, 1962.
5. Iowa State Highway Maintenance Study. Highway Research Board Sp. Rept. 65, Supp. I, pp. 150-151, 1961.
6. Specifications for High-Strength Low-Alloy Steel, ASTM Designation: A 242-63T. ASTM Standards 1963, Pt. 4, pp. 257-259.
7. Buck, D. M. Influences of Very Low Percentages of Copper in Retarding the Corrosion of Steel. Proc. ASTM, Vol. 19, Pt. II, pp. 224-237, 238-246, 1919.
8. Reports of Committee A-5, Corrosion of Iron and Steel. Proc. ASTM, 1916-1951.
9. Larrabee, C. P. Corrosion Resistance of High-Strength Low-Alloy Steels as Influenced by Composition and Environment. Corrosion, Vol. 9, pp. 259-271, 1953.
10. Jordan, H. V., et al. Sulfur Content of Rainwater and Atmosphere as Related to Crop Needs. USDA Tech. Bull. No. 1196, Superintendent of Documents, U.S. Govt. Print. Off., Washington, D.C.
11. Alpert, S. D., et al. Metal Towers for 650-kv Operation on Project EHV. Paper presented at AIEE Winter Gen. Mtg., New York, Feb. 1961.
12. Rawls, J. A. VEPCO 500-kv Line Advances New Design Ideas. Electrical World, Vol. 158, pp. 44-46, 72-73, Nov. 26, 1962.
13. Dinkaloo, John. The Steel Will Weather Naturally. Architectural Record, pp. 148-150, Aug. 1962.
14. John Deere Sticks of Steel. Architectural Forum, Vol. 121, No. 1, pp. 76-85, 1964.
15. Architecture: The Plowman's Palace. Time, Vol. 84, No. 6, pp. 64-65, Aug. 7, 1964.
16. Architectural Forum, Chicago Civic Center, Vol. 116, pp. 110, 129, May 1962.
17. Burg, A., and Hulbert, S. F. Predicting the Effectiveness of Highway Signs. Highway Research Board Bull. 324, pp. 1-11, 1962.
18. Metal Fence to Check Drifting Snow and Sand. Amer. Railway Eng. Assoc., Bull. 584, pp. 502-504, Feb. 1964; Ann. Proc. Amer. Railway Eng. Assoc., Vol. 65, 1964.
19. Hayes, J. M., and Maggard, S. P. Economic Possibilities of Corrosion-Resistant Low-Alloy Steel in Short Span Bridges. Proc. Amer. Inst. of Steel Constr., Nat. Eng. Conf., pp. 59-68, 1960.
20. Hayes, J. M., and Maggard, S. P. Economic Possibilities of Corrosion-Resistant Low-Alloy Steel in Welded I-Section Stringer Highway Bridges. Highway Research Board Proc., Vol. 41, pp. 125-162, 1962.
21. Hayes, J. M., and Maggard, S. P. Economic Possibilities of Corrosion-Resistant Low-Alloy Steel in Box Girder Highway Bridges. Highway Research Record No. 76, pp. 102-139, 1965.
22. LaQue, F. L., and Boylan, J. A. Effect of Composition of Steel on the Performance of Organic Coatings in Atmospheric Exposure. Corrosion, Vol. 9, pp. 237-241, 1953.
23. Copson, H. R., and Larrabee, C. P. Extra Durability of Paint on Low-Alloy Steels. ASTM Bull., Dec. 1959.
24. Dinkaloo, John. Bold and Direct Using Metal in a Strong Basic Way. Architectural Record, pp. 135-142, July 1964.