

Research Report
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Ohio River Suspension Bridges: An Inspection Report

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Introduction

For many years, suspension bridges have been employed to economic advantage where long uninterrupted spans were required. While they have been supplanted for most common applications by cantilever and arch bridges in the United States, suspension bridges are a valid design type. Two American suspension bridges have been in service for over 100 years. A new form of suspension bridge, the cable-stayed bridge, is widely used in Europe and is expected to be as popular in the United States.

The key to the success of suspension bridges lies in the use of high-strength wires that are consolidated into the main cables. These cables support very heavy loads, compared to common structural-steel members. This allows designers of suspension bridges to employ lower dead loads than necessary for other types of bridges for equivalent live loads and spans. Unfortunately, to achieve economy of construction, load-bearing redundancy is usually sacrificed in most suspension-bridge designs. If a main cable of a suspension bridge should break, the bridge would collapse in a catastrophic manner. Therefore, defects in the main cable wires of a suspension bridge may be significantly more critical than defects in structural members of other bridge types.

In August 1978, the Ohio Department of Transportation closed the U.S. Grant Bridge (US 23) over the Ohio River between Portsmouth, Ohio, and South Shore, Kentucky. Closure was due to increasing severity of corrosion, first detected in the main cables of the bridge in 1975. Besides inconveniencing area residents, closure created public and official concern about the structural integrity of suspension bridges under authority of the Kentucky Department of Transportation. The suspension bridges owned and maintained by Kentucky are the Maysville (US 68) Bridge at Maysville and the Ohio River (KY 17) Bridge at Covington.

A month after closure of the Portsmouth Bridge, a meeting was held in Frankfort to discuss inspection of the suspension bridges. Representatives from the Divisions of Bridges, Maintenance, and Research concluded that the focus of efforts should be on the Maysville Bridge due to its similarity to the Portsmouth Bridge.

While the Portsmouth Bridge problems were attributed to corrosion, the exact type(s) of corrosion was not known. There was a compelling need to determine what types of corrosion would attack suspension bridge cables, how this action could be detected, and how the severity of any corrosive attack could be assessed.

In the past, KYDOT had performed yearly inspections of the suspension bridges. However, access to the interior of the cables, located outside the anchorages,

was prevented after wire was wrapped around the cables. As an interim measure, inspection ports or windows were installed on the main cables outside the anchorages. These ports were to be permanent installations that would facilitate future inspection of the cables. The ports were also to be used to check for water seepage into the cables. The Division of Bridges was assigned the task to design the inspection ports.

The Research Program was assigned responsibility for gathering relevant background information. Several bridge authorities were consulted, including the Golden Gate, the Machinac, and the Triborough Bridge staffs. Their maintenance situations differed from those of KYDOT. The larger suspension bridges receive continuous maintenance, which is not afforded a smaller bridge like the one at Maysville. With one exception, no corrosion problems had been experienced by those authorities, although the extent of their in-depth inspection for this type of problem was limited or nonexistent.

Information on corrosion related to bridge wire and some historical data will be compiled in a pending report, "Kentucky Suspension Bridges and Corrosion," to be issued soon by the Kentucky Transportation Research Program. During the preparation of that report, it became clear that past research pertaining to the subject of bridge wire corrosion was inadequate.

Much of the existing literature dealt with the Portsmouth Bridge, which had experienced corrosion difficulties 30 years ago. The bridge was originally completed in 1927. Ungalvanized or bright wires were used in the main cables. The main cables were of parallel wire-strand construction. The cable wires were coated with red-lead paint and wrapped with galvanized wire, as was common practice at that time. In 1939, general corrosion and many broken wires were detected in the anchorages of the bridge. The breaks were concentrated at the strand anchor shoes. Most of the breaks were in the Ohio anchorage on the upstream side. A year later, the bridge was recabled with galvanized structural strand.

At the time of the first failure, little was known about corrosion cracking. Samples of the bright wire were tested for mechanical properties at Carnegie Institute of Technology. The investigator, without performing any tests to substantiate his claim, hypothesized that the first Portsmouth cable problem was caused by stress corrosion (1). Later, at the National Bureau of Standards, Pollard (2) produced laboratory stress corrosion fractures in Portsmouth wire specimens immersed in aqueous solutions of nitrates. Unfortunately, many recent researchers have mistakenly presumed that Pollard proved

the cause of the first cable problems to be stress corrosion.

Some facts tend to contradict that assumption. Wire breaks were observed in the anchorages, where wires were exposed to flood waters (on the Ohio side) and dampness. The dampness may have been precipitated by moist sand, used as a counterweight in the anchorages. When the bridge was recabled in 1940, the anchorage eyebars were lengthened and extended outside the anchor houses. This was done in an effort to keep the new wires out of the damp anchor houses and above the high-water level of the river. Moisture in the cables at the anchorages was probably not of the same chemical content as rainwater. It would be difficult to deduce how nitrates could be furnished, in harmful concentrations, by flood water and condensed moisture. If nitrates were in rainwater that filtered down the cables, a larger amount of the corrodant should have been on the wires at points outside the anchorages. However, few breaks were detected at those locations.

Another consideration is that most of the breaks occurred on the upstream cable. The dead load was almost evenly distributed on the cables. However, due to the presence of a sidewalk on the downstream side, the live load was greater on the upstream cable. Dead load has a predominant effect on stress corrosion and live load a more important effect on corrosion fatigue. Therefore, it could be argued that corrosion fatigue was the active mechanism that led to recabbling the first bridge.

In June 1974, Modjeski and Masters Consulting Engineers were hired by the Ohio Department of Transportation to inspect the U.S. Grant Bridge. For most of the service life of the bridge, it had been under private ownership. A superficial inspection revealed rust strains on the bottom of the cable wrapping at several locations. In August 1975, a more detailed inspection, which entailed unwrapping cover wire for six panels (band-to-band), revealed localized rust on the cables and a few broken wires. In 1978, work was undertaken to remove all the wire wrapping and rehabilitate the cables by brushing off the rust and rewrapping the cables with a neoprene-hypalon protection system. At that time, many breaks were detected on the newly unwrapped portions of the cables. In addition, the number of breaks detected at previously unwrapped locations had increased significantly. At that time, Battelle-Columbus Laboratories was employed to determine the cause of wire breakage. Results of the Battelle investigation were presented in preliminary form in late June 1978; and shortly thereafter, the bridge was closed (3).

A subsequent Battelle report indicated wires failed due to stress-corrosion cracking (4). That report also stated the condition of the bridge would worsen with time and there was no practical way to rehabilitate the cables. No judgment was made as to the physical condition of the bridge in the Battelle report.

The main problem (for subsequent investigators)

with the Battelle analysis is that insufficient work was done to conclude that stress corrosion was the cause of wire breakage. Even with detailed investigations, there is often disagreement as to the cause of a service failure. In their analysis of the bridge collapse at Point Pleasant, researchers at Battelle concluded stress corrosion was the cause of failure of that eyebar-suspension bridge (5). However, the U.S. Steel Laboratory found evidence that corrosion fatigue was involved.

The basis for the Battelle conclusions about the Portsmouth cables was the detection of branched cracking, multiple cracks, and sulfides on the fracture surfaces. Those features may also be related to other forms of corrosion cracking. Also, it should be pointed out that Battelle did not identify a specific atmospheric pollutant existing in damaging concentrations in the Portsmouth atmosphere.

Stress-corrosion tests were performed by Boeing Aircraft Corp for the FHWA (6) on uncoated and galvanized wires immersed in aqueous-sulfur environments. The specimens were notched and subjected to tensile stresses exceeding 90 ksi (620 MPa) for the duration of the tests (10-14 months). None of the 39 specimens used in the tests failed. Results of that work are seemingly in contradiction to the Battelle inference that aqueous sulfate/sulfides caused the problems at Portsmouth. Pollard (2) was unable to produce stress-corrosion cracking in bare Portsmouth Bridge wire immersed for 31 months in aqueous ammonium-sulfate solutions.

While stress-corrosion-related chemicals could evolve from the atmosphere, their concentration in moisture may be so slight that, in a stress-corrosion loading environment (i.e., a static tensile stress), the corrodants might not be active. However, in a fatigue-loading environment, the corrodants might have a detrimental effect. In many cases, suspension bridges are in a low-cycle fatigue environment.

There is an attendant implication in the term "stress corrosion" that suggests an unusually corrosive atmospheric condition exists, indigenous to the Portsmouth-South Shore area, causing the two wire-corrosion problems. It could be inferred that this corrosive atmosphere does not exist in locations where the Kentucky-maintained suspension bridges are located.

Descriptions of other forms of localized corrosion, which could cause wire breakage, were also included in the draft report "Kentucky Suspension Bridges and Corrosion." These include corrosion fatigue and hydrogen cracking. Neither of those mechanisms requires a specific corrodant, as does the classical concept of stress corrosion.

Historical literature revealed that bridge-cable corrosion problems are not uncommon and that at least three suspension bridges in the United States have collapsed due to that cause. Also, some human-related contributory factors may have promoted corrosion problems at Portsmouth. The pending report on sus-

pension bridges and corrosion concluded that, regardless of the active corrosive mechanisms in either Portsmouth corrosion problem, the main factor in the structural reliability of a suspension bridge is the condition of the corrosion-protection system.

In most modern bridges, the corrosion-protection system usually consists of galvanized coating of the wires, red-lead paint on the outer strands, and wire wrapping cable. Suitability of that system is suspect for suspension bridge applications where constant maintenance is not provided.

After preliminary investigations and review of the literature, Transportation Research Program personnel began work to determine steps necessary to make an accurate assessment of the structural integrity of the two suspension bridges owned by Kentucky. Visual field inspections were made of the bridges at Portsmouth, Covington, and Maysville. Also, a traffic survey was performed at Maysville and contact was made with the Ohio Department of Environmental Protection to determine if atmospheric differences existed between Maysville and Portsmouth.

Inspection of the Portsmouth Bridge

From May 9, 1979, to completion in December 1979, Research Program personnel monitored recabling of the Portsmouth Bridge (Figure 1). The work was performed by the American Bridge Division of U.S. Steel Corporation. Modjeski and Masters were the consultants, and M. Baum was the resident engineer for the Ohio Department of Transportation.

Early inspections of the bridge were made in May and June of 1979. The cables had been unwrapped prior to the winter of 1978; however, at the time of these early inspections, the cable bands were still in place. During those inspections, a survey was made of the condition of the exterior strands. Additionally, photographs of the cables were made and samples of broken wires obtained.

Exterior strands were severely corroded in many locations. At points, all exterior strands showed ferrous corrosion or rust (Figure 2). That type of corrosion was either evident on all exterior strands for an entire panel (band-to-band) or concentrated in the lower strands for the entire panel length. Severe rust was present for more than one consecutive panel, with the exception of panel 66-67, downstream, on the Kentucky side. Contrary to expectations, severe rusting was observed on both horizontal and inclined portions of the cables. Panels where cables were steeply inclined generally contained more severe rusting than adjacent panels of less inclination.

Only one panel (66-67), downstream, had severe rusting on the Kentucky side span. Thirty-three of the 40 main-span panels on the downstream cable were severely rusted, while eleven panels on the upstream cable were seriously rusted. These were located on the lowest (shallowest) portion of the cable. Twelve panels of each cable on the Ohio side contained severe rust.

Corrosion of the zinc coating was evident on the exterior strands of the main cables. It was present in the form of a powdery white coating on the wires. On the lightly corroded strands, the white coating was tenaciously attached to the individual wires. In areas where the heavy zinc corrosion occurred, but little or no visible rusting was identified, the white powder assumed a thick

fluffy texture, and could be removed by lightly scraping with a finger nail. Usually, the steel wire revealed below the heavily-corroded zinc was lightly rusted and slightly pitted. Spotted rust was visible in most areas where heavy zinc corrosion occurred. However, superficial rust was not evident in areas of light zinc corrosion. In certain places, the aqueous corrodant had a washing action on the cables. In these areas, ferrous corrosion and pitting were severe. These locations could be identified by the absence of the zinc corrosion product.

Nearly all portions of the cables not severely rusted exhibited large amounts of zinc corrosion. This included 19 panels on each of the downstream and upstream cables of the Kentucky span. Seven panels of the downstream cable and 28 panels on the upstream cable of the main span showed heavy zinc corrosion, but no appreciable rusting. Seven panels on both the downstream and



Figure 1. The Portsmouth Bridge early in the recabling operation.

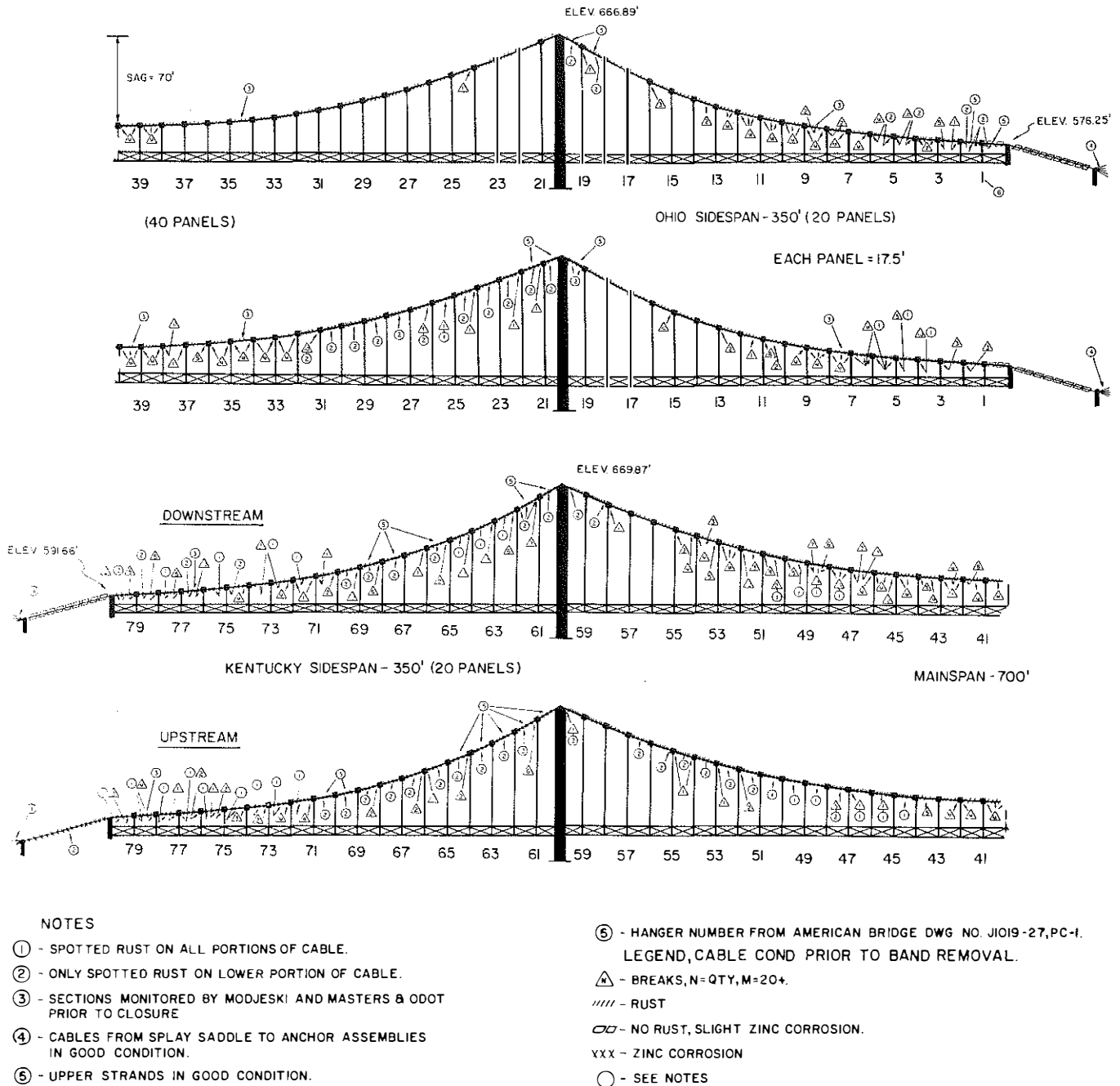


Figure 2. U. S. Grant Bridge corrosion survey (May - June, 1979).

upstream cables on the Ohio span also exhibited that behavior.

Portions of cable between the bents and the splay saddles appeared in good condition, with the exception of the downstream Kentucky side span, which had some spotted rust. Most individually exposed structural (helical) strands, from the splay saddles to the anchor assemblies, were also in good condition, except for some severe zinc corrosion on the lower wires of a few strands. Panels 0-1 of both Ohio span cables were also in good condition.

Most of the breaks detected prior to removal of the bands were located in the lower portion of the exterior strands. Many broken wires were clustered where (1) most of the galvanizing was depleted by corrosion, (2) the wires were rusted severely, and (3) the inclination of the cables was shallow. In areas where nominal rust was evident, breaks were infrequent. But a few were found, individually or clustered, in groups up to ten, usually near the cable bands. This characteristic was prevalent in many panels on the Kentucky span and on the steeply inclined

portions of the main span and Ohio span. Few breaks were observed in panels having steep slopes, even when corrosion was severe.

Prior to the band removal, all parties who had inspected the cables felt the bridge was structurally sound. Some 300-400 breaks had been discovered on the cables prior to band removal. Superficial inspection detected section losses exceeding 10 percent in both cables.

In early June 1979, 350 feet (107m) of the center span was removed as part of the cable replacement program. Remaining portions of the truss were supported by temporary stays and A-frames. Before dismantling the damaged cables, the suspender cables and bands were removed. When this was accomplished, several important discoveries were made.

Many of the drain holes, located in the packing of the vertically split bands, were improperly installed and did not allow water to drain from the cables. Though the lead-wool packing had been properly driven into the gaps between the band halves, water had frozen between them and three or four bands had suffered pop-outs. Many new

wire breaks were found at points previously covered by the bands. Under one band, breaks were observed on every exterior strand. Many breaks were discovered on the upper strands. Inspection of the interior strands revealed large amounts of corrosion and additional breaks (Figure 3). Unfortunately, the construction schedule precluded a detailed inspection of the interior strands.

The main cables were removed, strand-by-strand, between June 27 and July 18, 1979. Hundreds of new breaks were found in the upper interior strands. Most of those were detected after the strands had been pulled through sheaves and grounded on the river bank. A rough count of number of breaks per strand was made during the removal operation. It is estimated that each cable had about 350 broken wires of the 1,015 total wires per cable. This probably represents a 20-30 percent loss in the load-carrying capacity of the cables.

The Portsmouth cable problem was caused by a massive failure of the cable protection system (i.e., the cable wrapping system and wire galvanizing). Pictures furnished by the Ohio Department of Transportation

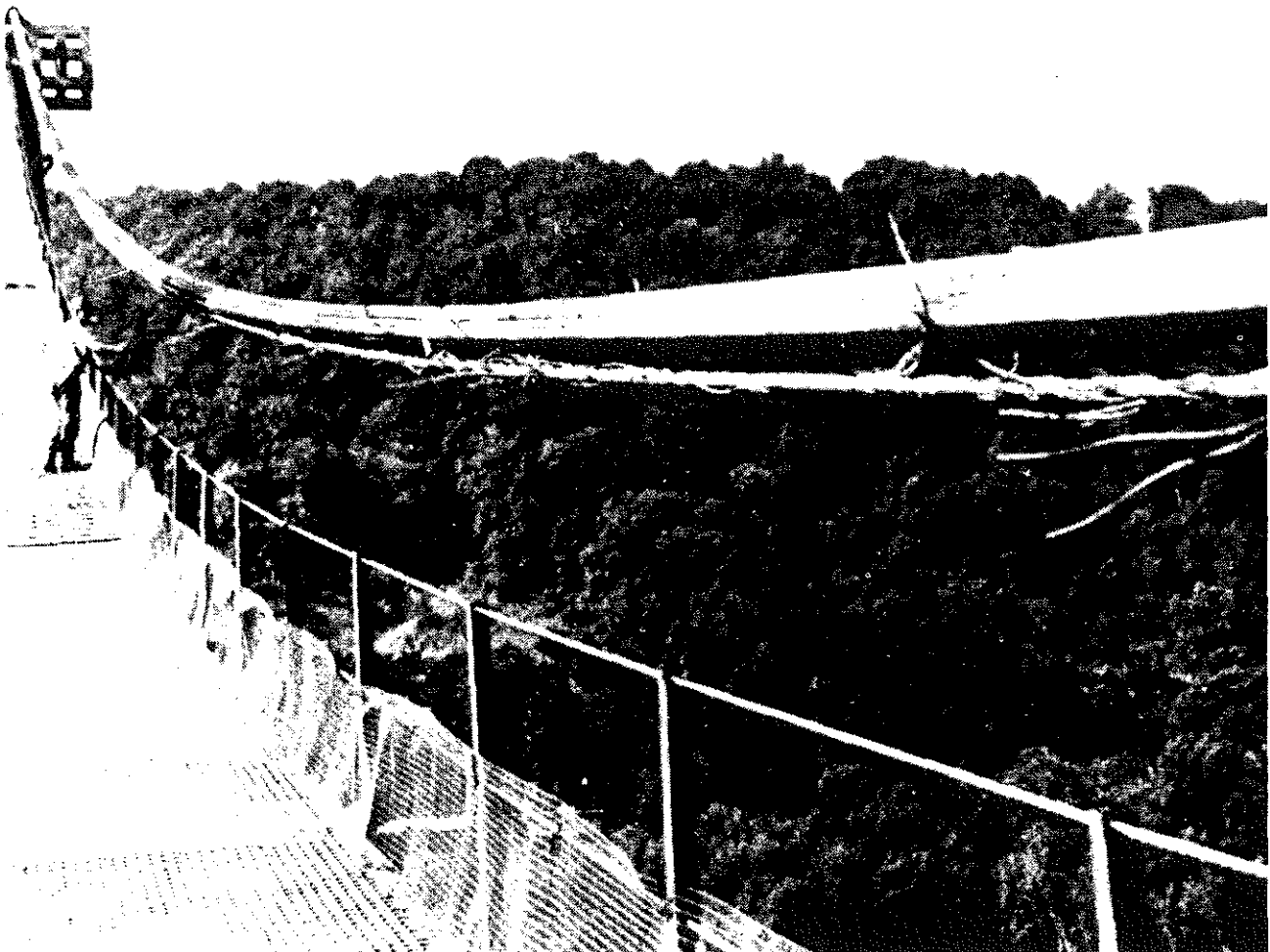


Figure 3. Portsmouth Bridge, Ohio span, downstream after band removal.

showed the cable wrapping to be badly corroded. Apparently, failure to maintain the paint protection on the cables led to localized corrosion of the wrapping wire and allowed more atmospheric moisture (i.e., rain and melted ice) into the cables than would be normally anticipated. Inefficient drain holes retained water, which probably contained atmospheric corrodants. The combined effect of moisture, corrodants, and applied and residual stresses eventually led to wire breakage.

Figure 4 shows a corroded section of the downstream cable that typifies the failure process. Localized rust on the upper strands was caused by a failure of the wire wrapping adjacent to the rusted strands. General corrosion was severe in the upper strands. Very little white zinc corrosion product remained on the rusted portion of the upper strands. These facts indicate water leaked through the upper strands with a washing effect. Other portions of the upper strands in that panel were in good condition. Apparently, water settled in the lower portions of the cable. Because of poor drainage and mild slope of the panel, the aqueous corrodant maintained long-term contact with the lower strands and was more effective in causing wire breakage. Also, the lower strands may have experienced higher tensile loads than the upper strands. This would contribute to a corrosion-cracking type failure at points along the panel away from the bands.

A relationship may exist between the large number of breaks at the suspension points (cable bands) and concentration of applied stresses at these locations. Observers indicated breaks were more frequently encountered at suspension points where the change in slope of the cables between panels was greatest. However, that fact was not verified. It should be noted that, in panels where the effects of large-scale corrosion were not extreme, few breaks were encountered near suspension points. Some of those breaks occurred near ends of the solid aluminum fillers. Possibly, the galvanized coating



Figure 4. Portsmouth Bridge, main span, downstream side, at Panel 45-46.

of the wires was damaged by the sharp filler ends during installation. Another possibility is that space between the closely-fitted fillers retained moisture, allowing intense local corrosive attack.

Several specimens of strand which had no exterior corrosion were obtained. Upon separating these specimens, no interior corrosion was observed. However, faying surfaces of individual wires exhibited signs of fretting, leading to erosion of galvanizing and slight plastic deformation of the wire. The wires bore continuous longitudinal marks from contact with neighboring wires in the same layer and transverse stripes from the adjacent layer of wires, which had opposite lay.

Specimens of the Portsmouth structural strand also indicated capillary action allowed moisture to be retained in the cables. Some strand specimens appeared to be in good condition with only slight zinc corrosion near the wire interfaces. Splayed specimens revealed zinc corrosion and spotted rust on the backside of the exterior wires. The second layer of wires was covered with corrosion products. The third layer of wires was in good condition, as were the other interior layers (Figure 5).

Structural strand specimens exhibiting washing showed severe surface rust, pitting, and little retention of the white zinc corrosion product on the exterior layer of wires. Despite poor external appearance, the interior corrosion was no worse than in specimens previously described.

Severely corroded wires, from locations of poor drainage, were externally similar to the washed specimens, except for the presence of the white, zinc corrosion product. Internal inspection revealed all wires to be severely corroded. Fretting marks were visible on those specimens, except at points where corrosion had depleted the adjacent wires to the extent they were no longer in close contact. Where close contact was maintained, the neighboring wires wiped away the corrosion product, exposing the bare metal.

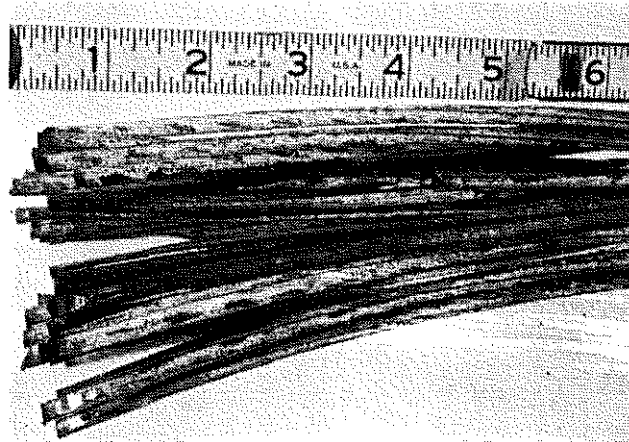


Figure 5. Splayed wire specimen from the Portsmouth Bridge. Note uncorroded interior wires.

The ends of broken wires exhibited two types of fracture morphology. Some wires had fractures transverse to the longitudinal axes of wires. More commonly, a transverse fracture emanated from the surface and penetrated about halfway through the wire. Thereafter, the fracture reoriented itself 45 degrees to the longitudinal axis and penetrated through the wire. None of the strand specimens revealed fractures in the internal layers that were not preceded by fractures in the external layer of wires. Some broken wire specimens had a fracture spacing of less than 3 inches (75 mm). All wire specimens having corrosion fractures exhibited complete zinc corrosion and, at best, some light surface rusting.

The preponderance of wire breaks on the main span and Ohio span, compared to the Kentucky span, is attributable to the more extreme deterioration of cable-protection systems at those locations. Unfortunately, no accurate determination was made of the difference in number of breaks in the two cables.

Presence of long-term moisture in the cables definitely should be avoided. There is much doubt about the ability of conventional galvanized wire wrapping to protect the underlying cables. Small amounts of moisture contacting the wires in situations such as washing or condensation-evaporation may cause accelerated wire deterioration, or even cracking (especially at points of high stress concentrations, such as band suspension points). Cable deterioration can be greatly accelerated by the pre-

sence of corrosive pollutants, such as sulfates, chlorides, and nitrates, in the moisture.

The corrosive decay of galvanized structural strand was observed to occur in four stages. During Stage One, the strand is in "as new" condition. The zinc coating has a bright metallic appearance, though some slight spot corrosion of the zinc may be evident in the form of a thin white powdery coating. The strand is in good condition during Stage Two. Exposure to the atmosphere has given the zinc a dull-gray appearance. The white corroded-zinc film may be present near the interfaces and on the exterior surfaces of the wires. If the white film is removed by scraping, no rust is evident. The second layer of wires may be in worse superficial condition than the outer layer, but, as long as the outer layer of wires is stable, the interior wires will probably remain structurally sound.

Much of the strand is covered with a thick white zinc corrosion product in Stage Three. Spotted rust is also visible on the wires. When the corrosion product is scraped off, the steel under the surface reveals some rust and pitting. Wire breakage is possible during this stage; however, the breaks will not be clustered in large numbers, except near points of high stress concentration.

During Stage Four, the strand will be severely rusted and pitted. Some zinc corrosion will be displaced by corrosion of the underlying steel (rust). The wires will have a speckled brownish-red and white appearance. If loading and corrosion conditions are severe, the strand will develop many fractures and will eventually fail.

Inspection of the Maysville Bridge

Inspection of the Maysville Bridge (Figure 6) began in June 1979. The bridge had been in continuous service for 49 years. It had no known history of corrosion problems. The first three inspections (June-August 1979) consisted of external observation of the wrapped cables and the splayed structural strands inside the bridge anchorages.

The cables were last painted in 1974. Externally, the paint was in fair condition. Transverse cracks had developed in the paint on the upper portion of the cables (Figure 7). Paint had peeled off lower surfaces of the cable in spots. That usually happened where the inclination of the cables was slight. The upper surface of the downstream, Kentucky side, span cable wrapping was in poor condition from the bent to the anchorage. At that location, the cable had been subject to considerable foot traffic (the cables were equipped with hand rails). Many points on the sides of the cables, adjacent to the bands, showed signs of frequent peeling in the previous top coat of paint.

The suspender cables were in good condition, except for a few hangers that had been damaged by passing vehicles. These have subsequently been repaired. Unlike

the Portsmouth Bridge, which was designed to have drain holes on each band, only two drain holes were provided for each cable on the Maysville Bridge. These were located in the lower packing of the bands, in the center of the midspan, bordering Panel 69-69. The cable was horizontal between the drain-equipped bands.

Inspection of bands, which had no drain holes, revealed that packing on the underside of several bands had been forced out. Adjacent to many of these pop-outs were rust-colored stains on the cast-steel band halves (Figure 8). During an early inspection, after a rain, water was seen dripping from the stained portion of one band that had suffered a packing pop-out.

Entrance to the anchor chambers was made through manholes on the bridge sidewalk. An access ladder descended from each manhole, some 40 feet (12 m), to the anchor-house floor. The ladders did not have safety rings required by OSHA regulations. The anchorages had two interconnected chambers, each housing one anchor assembly and cable. The chambers were dark and unlit. The chamber floors and pedestals were dusty, with some debris scattered on the floors. The chamber walls and ceilings showed a large amount of efflorescence and

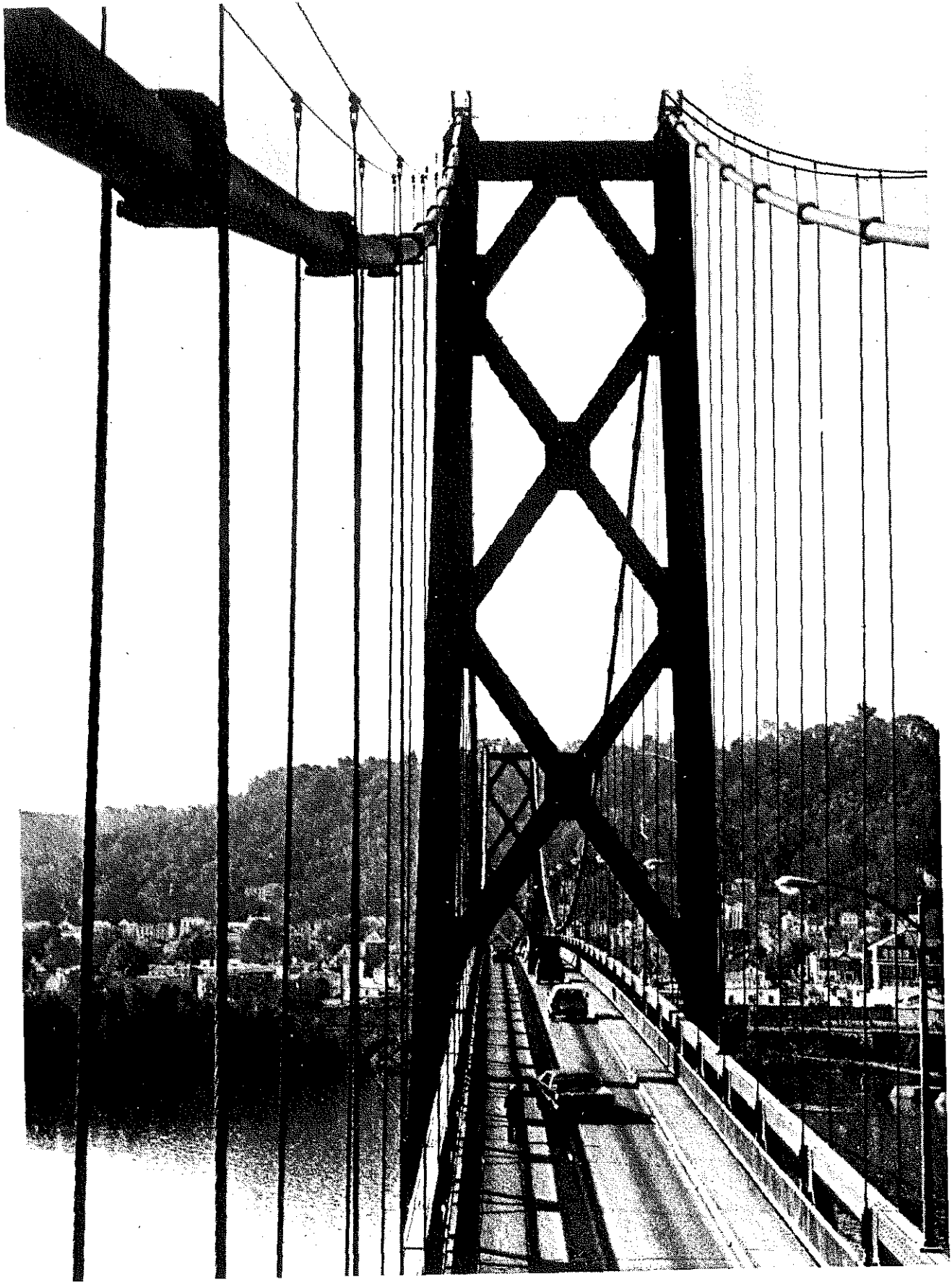


Figure 6. The Maysville Bridge.

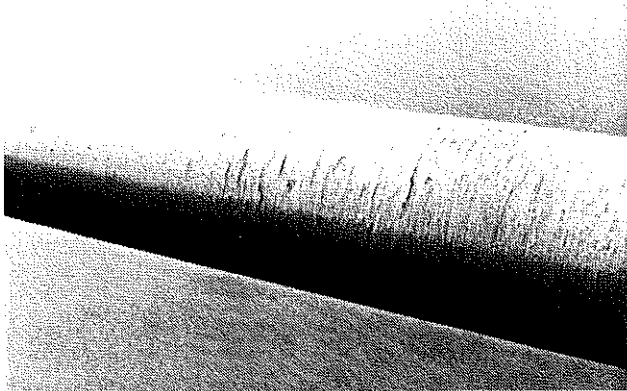


Figure 7. Transverse cracks in paint on the main cables of the Maysville Bridge.

were covered with a black mastic compound, which was probably employed as a water sealant. Graffiti was present on the walls, indicating that chambers had been trespassed and violated on several occasions. Small drains were located near the ladder bases. However, a large damp spot adjacent to the drain of the downstream Ohio chamber indicated this drain was clogged.

Each anchor chamber had two windows; one, mounted on the sidewall, and the other on the headwall facing the river. These were fitted only with bird screen. The presence of many bird skeletons on the anchor-house floors indicated that most of the screens were not functional. The sidewall windows were located adjacent to and slightly elevated over the anchor assemblies.

The splay saddles were mounted on the chamber headwalls. Sixty-five structural strands radiated from each saddle to an anchor assembly resting on the highest of three concrete pedestals (Figure 9). The anchor assemblies consisted of rows of large vertically mounted steel plates. The strands were fastened in the plates by steel end

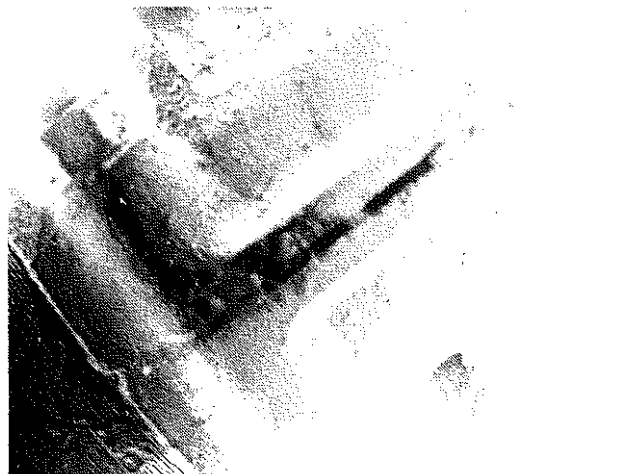


Figure 8. Pop-out and stain on the main span, downstream cable at hanger U-61.

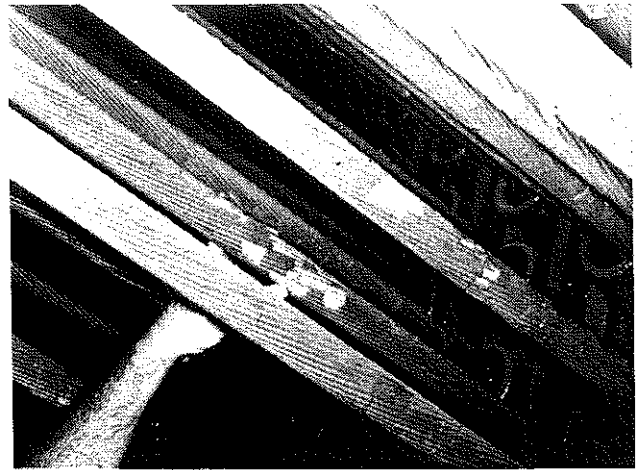


Figure 9. Maysville Bridge anchor assembly. Note the strands enter the anchor assembly through sleeve bushings.

sockets bearing against cast-steel blocks that were bolted between the plates. Cast-steel sleeve bushings were attached to the strands for protection where the strands passed between the bearing blocks. The anchor assemblies were pinned to eyebars, which were partially embedded in concrete. The strands, observed to be in good-to-fair condition, had a base coat of red-lead primer and a top coat of green paint (Figure 10). Painting appeared to have been poorly executed. In many places, the green paint was not applied over primer. Where the green topcoat was present, it was very thick and brittle. The paint and primer had chipped off many strands. In spots, the galvanizing on the strands was depleted, leaving the usual chalky white corrosion product that may be presumed to be zinc oxide. In closely inspected areas, no rust was detected under the corroded zinc. The condition of the strands in the anchorages can be described as Stage Two deterioration. The end portion of strands in the

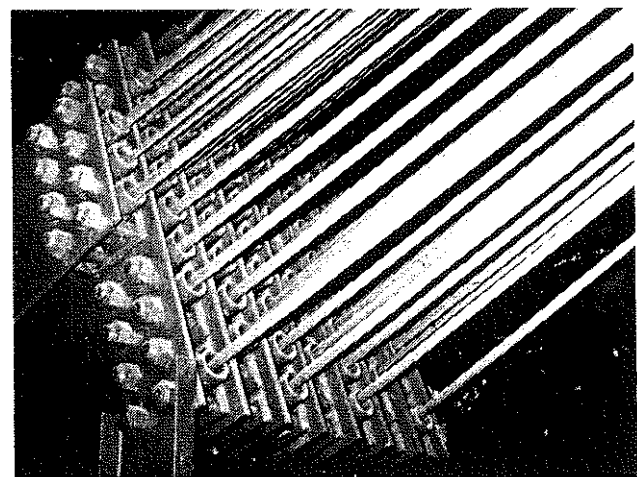


Figure 10. Strands in the Ohio downstream anchor house. Note white zinc corrosion deposits on the strands.

sleeve bushings appeared to be in worse condition. There was considerable loose rust and chipped paint in the recesses of the sleeves. Due to poor lighting, the exact condition of the strands inside the sleeves could not be determined. At the splay saddle in the Ohio upstream chamber, some washing of red lead or rust from the exterior cable was visible on the lower strands.

The eyebars and the adjacent portion of the anchor assemblies were rusting. The paint work did not appear to be satisfactory, especially in areas of poor physical access. Scaling and rust were detected along the eyebars at points where these were embedded in the concrete. However, the

loss of section did not appear to be appreciable. The open sidewall window next to the anchor assemblies promoted corrosion by allowing rainwater and ambient moisture to collect on the eyebars and anchor assemblies. Rusting was most extensive in the Kentucky downstream anchorage.

During the third week of August 1979, bridge maintenance personnel installed seven inspection ports on the Maysville Bridge (Figures 11 and 12). Those were located at Panels 0-1, 7-9, 59-61, and 69-69 on the Ohio span and the main span (Figure 13). The ports were

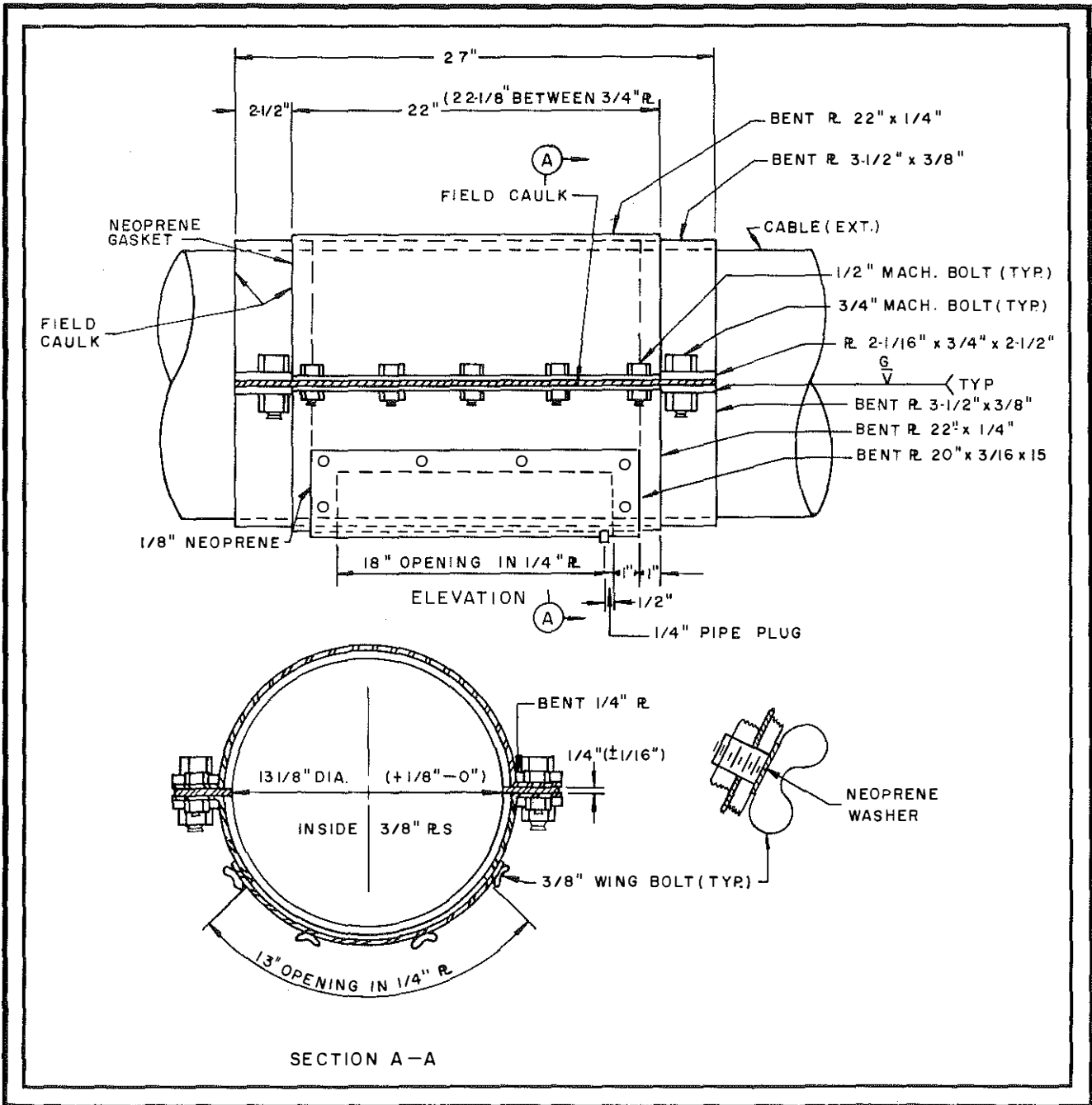


Figure 11. Cable inspection port used on the Maysville Bridge.

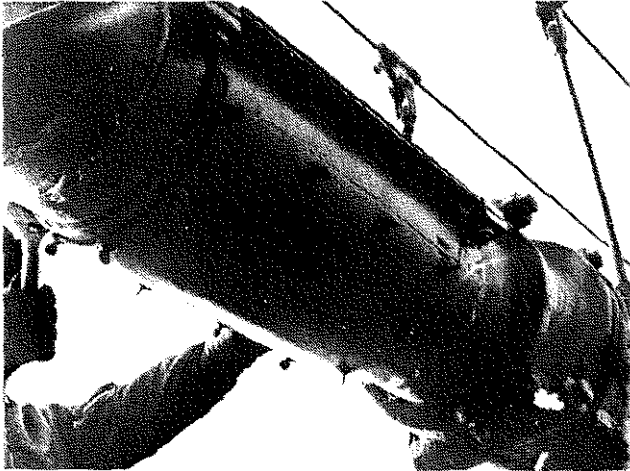


Figure 12. Installation of an inspection port on the Maysville Bridge.

installed near bands having pop-outs and on panels where the cable paint had deteriorated.

Prior to installation of the inspection-port outer bands, paint was removed from the cable with a wire brush. The outer bands were attached and tightened. Then, the wrapping wire between the bands was broken and removed. The lower aluminum fillers, in the unwrapped portion of the cable between the bands, were removed with bolt cutters. Before installing the port cover plates, the exterior strands of the cables were inspected and photographed. After the covers were in place, all seams were thoroughly caulked with silicone sealant.

The exposed cables revealed that, unlike the Portsmouth Bridge, the Maysville Bridge strands were individually covered with a generous coating of red lead. Unfortunately, that coating was deteriorating, and in many locations, the galvanizing was depleted.

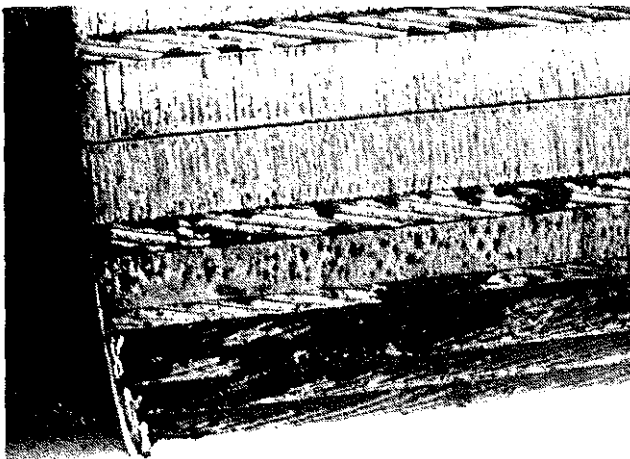


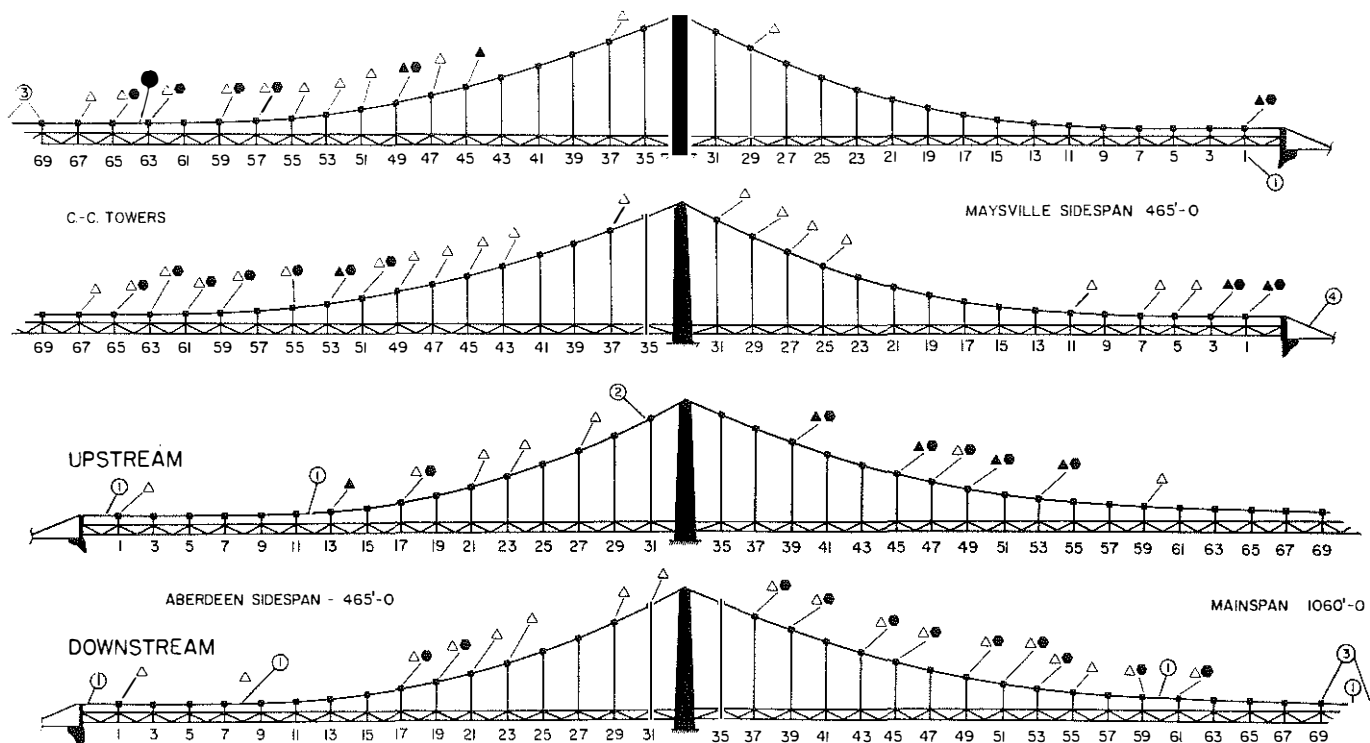
Figure 13. Inspection port on Panel 65-63 on the upstream main span cable. Note the rust spots and red lead coating.

At all inspection sites, the bottom strands showed the greatest corrosion of the zinc coating. All exterior strands in Panels 0-1 and 69-69 on the downstream cable were in very good condition. The upper strands of the downstream cable, in Panels 11-13 and 65-63, were also in good (early Stage Two) condition. However, many bottom strands had extensive zinc corrosion. All the external strands on the upstream inspection sites had zinc corrosion. Several rust spots were visible on the lower strands at Panel 59-61 downstream and at Panel 65-63 upstream (Figure 13). Galvanizing in those areas was severely depleted. Except for the few large rust spots, no pitting or light rust was detected under the zinc oxide. That indicated Stage Three corrosion was starting at susceptible locations.

At several sites, a small quantity of water seeped from the cables when the wrapping wire was removed. The red-lead coating on the lower strands was disintegrating in those locations, and the layer of corroded zinc was thicker than on the upper strands. Some water probably seeped to the lower portions of the cable between the wrapping wire and strands. The interior lower portion of removed wrapping wire was corroded and had spotted rust. Apparently, some moisture seeped through the lower portions of the wrapping wire, froze, and caused the paint to peel.

On December 5, 1979, A. Blankenship and B. Crace of Bridge Maintenance, M. Baum of the Ohio Department of Transportation, and Research Program personnel performed a follow-up examination of the inspection ports. At that time, a survey was made of the band-packing disturbance (Figure 14). Several days before the inspection was made, the Maysville area had been subjected to a heavy rain. Water was dripping from popped-out packing at many band locations. When most of the inspection ports were opened, several quarts of water spewed from the cable. Since the port caulking was in excellent condition at all locations, it is presumed that water entered the cables at the bands or through the wrapping wire. Red lead residue was found on the inspection port covers located on the bottom face of the cables. This indicates a flow of water in the cables sufficient to cause washing. As the closed inspection ports had collected water, drain plugs were omitted from the port cover plates on reassembly.

Inspection of the packing pop-outs was conducted from the sidewalk using binoculars. While all the packing pop-outs were detected, it is possible that some seepage was overlooked. This would be especially true of the upstream cable, which was across the roadway from the sidewalk. The frequency of band pop-outs indicates that, despite the wire wrapping, the cables are virtually porous. The presence of pop-outs near the towers shows that a significant amount of water can be entrained, either at wrapping discontinuities along a single panel or at a sealing failure on a band. Seepage of water from a band that is one panel lower than another band with a pop-out



- ① - LOCATION OF INSPECTION PORT.
- ② - RUST BETWEEN BAND AND WRAPPING WIRE.
- ③ - DRAIN HOLE IN PACKING.
- ④ - PAINT ON CABLE POOR CONDITION.
- ⑤ - HANGER NO.'S FROM MC CLINTOCK-MARSHALL CONSTRUCTION DWG'S 5883-7E8; 5883-87E5; 5883-7,E6 & 5883-7,E6.

LEGEND

- △ - PACKING POP-OUT BETWEEN BAND HALVES.
- - RUST DEPOSIT ON BOTTOM SIDE OF BANDS DEPOSITED BY WATER SEEPAGE FROM CABLE.
- ▲ - PACKING POP-OUT, WATER DRIPPING FROM PACKING.

Figure 14. Maysville Bridge pop-out and water seepage survey.

indicates that water may be retained at the bands. This retention may be created by buildup or bridging of corrosion products and red lead near the pop-out.

No wire breaks were observed on the Maysville Bridge during any inspection. At that time, it was reasonable to conclude that the inspection sites chosen are representative of the entire bridge, with the possible exception of several locations on the Maysville span. Although the inspection ports allow limited examination, the accessible lower-exterior strands may be considered "worst-case" examples for the cables between bands.

The condition of the strands is of concern at suspension points under the bands. Detection of pop-outs and water seepage indicates moisture may be present at points of high stress concentration. At bands where pop-outs have been observed, washing and partial damming of water may accelerate deterioration of the galvanized coating on the wires. Inasmuch as corrosion-fracture resistance of corroded wire seems to be poor and stress at the bands are high, those would be the most

likely locations for finding broken wires. If further inspection reveals that water seepage is not associated with damming at band pop-outs, suspension points that had no pop-outs would be suspect.

Many concerned citizens believe the Portsmouth Bridge problems are a warning of impending failure of the Maysville Bridge. Conversely, some authorities consider the Portsmouth Bridge problems to be an isolated phenomena related to the particular environment of Portsmouth. The truth lies somewhere between those views. Certainly, the problems at Portsmouth served as a warning that a similar situation might arise at Maysville. However, the structural integrity of the Maysville Bridge does not appear to be impaired at this time. More work is necessary to verify that assumption.

There are several reasons why the Maysville Bridge has endured for nearly 50 years and the Portsmouth Bridge had failed twice in 53 years. The corrosion protection of the Maysville Bridge was superior to either of the Portsmouth Bridge cable-protection schemes. The first Portsmouth failure may be attributed to a design feature

that allowed one anchorage to be submerged below flood waters. The selection of ungalvanized wire was also instrumental in the early failure. It should be noted that after the first Portsmouth failure, American suspension bridge designers abstained from using bare ungalvanized wire.

The second Portsmouth Bridge cables, while similar to the Maysville Bridge in quality of galvanized protection, did not possess the lavish red-lead topcoat that was on strands of the Maysville Bridge. Much of the difference in the condition of the two bridges may be attributed to that one feature. The addition of red-lead topcoats to individual galvanized strands was not common practice. The designers of the Maysville Bridge exhibited great foresight in doing that, for it probably prevented severe corrosion damage to the cables. The drains designed for the second Portsmouth cable consisted of 3/8-inch (10-mm) holes drilled through the driven lead-wool packing. The resulting holes rarely penetrated through the packing. Those which succeeded were probably prone to clogging.

The Portsmouth cables were badly corroded prior to the discovery of broken wires in the cables. The detection of large rust stains on the undersides of the cables in 1974 indicated either they were not painted often enough or the paint used had poor sealing qualities. The Portsmouth cables also lacked handrails, preventing inspectors from walking the cables and assessing the condition of the wrapping wire.

The assumption has been made that airborne pollutants, combined with atmospheric moisture, greatly contributed to the Portsmouth cable problems. Over the life of the bridge, the Portsmouth area had a concentration of heavy industry located within 3 miles (5 kilometers) of the bridge. Area residents reported the pollution was worse through the 1960's than today. While the environs of the Maysville Bridge consisted mainly of residences and small businesses, many chimneys are in close proximity to the bridge. Railroad tracks run under both the Portsmouth and Maysville Bridges. In the last few years, four power plants have been, or are being, constructed in the Maysville area. All have tall smokestacks that allow pollutants to travel over long distances before settling. In the future, the Maysville area may have more pollution problems than Portsmouth.

In August 1979, Research Program personnel interviewed S. Giles, Air Division Field Supervisor of the Ohio Environmental Protection Agency for the areas neighboring the Maysville and Portsmouth Bridges. Mr. Giles furnished information concerning SO₂ and suspended particulates taken by continuous monitors in 1978. Measurements of both types of pollutants were well below federal standards. However, Mr. Giles explained that concentrations of these pollutants were expected to be considerably higher near roadways. The present atmospheres in both cities would not cause, or account for, any unusual type of corrosive attack.

No known, detailed weight measurements have been made of traffic over either bridge. The maximum, design service stress for the cables of both bridges is similar: 76.4 ksi (527 MPa) for the Portsmouth cables and 70.5 ksi (486 MPa) for the Maysville cables. Because cable sag is greater on the Maysville Bridge, it should be capable of carrying higher loads than the Portsmouth Bridge. In the winters of 1977 and 1978, fuel trucks having 90,000-pound (400-kN) gross weights were permitted on the Portsmouth Bridge. Heavy steel- and coal-hauling trucks have frequently used that bridge. One steel-hauling truck weighing 104,000 pounds (462 kN) crossed the bridge. That truck did not have an overweight permit. During the 1970's, many overweight trucks used the Maysville Bridge. However, strict enforcement of the weight limit has curtailed such abuse. Several times during inspection of the bridge, heavily-loaded semitrailer and concrete trucks were observed travelling in close succession, in violation of a posted 30-foot (9-m) minimum-spacing requirement.

Between August 8-10, 1979, a 48-hour traffic survey was conducted at the bridge. Results are shown in Table 1. The daily traffic volume was 12,300 vehicles. This figure is slightly lower than would be normally experienced due to a painting operation conducted on the bridge during that period. Several heavily loaded trucks were observed using the bridge late at night, when traffic on the bridge was otherwise sparse.

Since extensive construction activities are being conducted in the Maysville area, the bridge may be expected to carry considerable heavy traffic in the foreseeable future. Unfortunately, traffic flow across both the Maysville and Portsmouth Bridges is poor. All approach spans exit to either stop signs or stop lights, causing a large number of vehicles to be stopped on the bridges during peak periods.

Table 1. Traffic Survey on the Maysville Bridge (48 hours) for Both Lanes.

Type of Vehicle	Count	Percentage
Autos and Pickups	22,678	92.23
Buses	10	0.04
SU-2A-4T	427	1.74
SU-2A-6T	412	1.67
SU-3A	161	0.65
SU-4A	5	0.02
C-3A	31	0.13
C-4A	74	0.30
C-5A	776	3.16
C-6A	12	0.05
C-7A	1	0.01
Total	24,587	100.00

Note: Survey conducted between 12:00 am on 8-8-79 and 12:00 am on 8-10-79.

When the Portsmouth Bridge was closed, it was considered to be in fair structural condition. However, after the bands were removed, the true severity of the wire corrosion cracking was revealed. Ironworkers dismantling

the truss observed deformed splice plates and sheared rivets. That indicated either the truss was being subjected to extremely heavy loads or the cables were losing their load-carrying capacity.

Inspection of the Covington Bridge

Inspections were made of the Ohio River Suspension Bridge at Covington in June and September of 1979 (Figure 15). The scope of work was similar to the examination of the Maysville Bridge; however, inspection ports were not installed into any of the cables.

The 113-year-old bridge has some history of corrosion damage to the original cables in the anchor chambers. Those anchorages were originally embedded in mortar. The mortar became damp, causing the exterior wires of several strands to corrode and break at the strand shoes. At the time of that occurrence, the bridge still had only two cables. It was estimated that corrosion damage had caused a loss of 13 percent of the strength of the cables. Damage detected in 1892 was repaired by splicing wire segments to the corroded wire ends. The work was completed in 1892, and for some time, the strand ends were encased in an oil bath (7).

In 1898, the bridge was rebuilt and two new cables were superimposed over the original ones. The new secondary cables were made of bare steel wire. To accommodate the secondary cables, separate anchorages were made for the Ohio side, and the original anchor houses were extended on the Kentucky side. The new cables were tied to the original ones using solid vertical bars to interconnect cable bands. Loading of the secondary cables was adjusted by tightening threaded sleeve nuts located on the bars. The secondary cables were added to allow electric street cars to run on the bridge.

Superficial visual examination of the wrapped cables revealed no major physical defects. The wrapping and paint appeared to be in good condition. The cables were last painted in 1974. Only a slight amount of chipped paint was detected, this being primarily in the original upstream cable at midspan where the cable borders the sidewalk. Some of the chipping appeared to be due to vandalism. Rust-colored stains were visible at some cable bands. The nature of those stains could not be ascertained due to lack of physical access to those places. During the inspection, water was detected dripping from the lower upstream cables near the low point of the cable at midspan. Leakage was slight and emanated from a splice point in the wrapping (Figure 16). Moderate rusting was detected on the suspender cables near the lower hangers. Previous experience had shown resulting corrosion damage to be slight (8). A high-voltage electric cable was leaking oil on the upstream original cable near the middle of the span. The oil may cause the paint to deteriorate in that area.

An inspection was also made on the secondary cable at the Kentucky-tower roller supports. The upper cables, located in the tower turrets, were covered with a thick layer of pigeon droppings. The stay cables were also covered with pigeon manure (Figure 17). Bird screen was in place on the turret apertures, but the pigeons had obviously penetrated that defense. One broken wire was detected on the downstream cable at the roller support. The original cables were not inspected at the tower.

The anchorages were given a thorough examination, due to history of wire corrosion at those locations. Inspection was made of all four original cable anchor houses. The upstream Kentucky secondary anchor-house entrance opened to the roadway. Traffic on the bridge prevented inspection in that anchorage.

All anchor-house entrances have two doors. The outer doors were paneled with a heavy steel screen, the inner doors were made of sheet steel. The doors had latches and hasps for padlocks. However, all entrances were without locks. At several locations, both doors were found partially open. At most of the other entrances, the solid inner doors were found open.

Stepladders were required to enter the anchorages elevated from the sidewalks. Entrance into the upstream Ohio original cable anchorage was hazardous; the ladder had to be placed on a sidewalk stairway. Most of the closed doors were partially jammed, making entry difficult. The anchor houses were unlit, and sunlight from the entrance was inadequate for inspection.

Three original anchor houses showed evidence of water leaking from the roofs of both upstream anchorages and the Kentucky downstream anchorage. Water seepage into the Ohio downstream anchorage was slight and the anchor assemblies and strands were not damaged. In other original anchorages, water had dripped onto the strands, eyebars, and anchor assemblies, causing a deterioration of a whitewash wall-and-ceiling coating. Wrought-iron roof beams were also rusted. The dissolved whitewash was deposited as a white residue at spots where leaks impinged on wires and anchor assemblies.

All metal surfaces in the anchorages were coated with a thick layer of red lead under a brown topcoat, which was apparently a primer. That paint was in good condition in all places where water had not leaked onto the cables. Leakage had deteriorated the paint and severely corroded underlying metal (Figure 18). Old wire breaks were observed at the three anchorages that had leakage problems. The number of breaks ranged from one

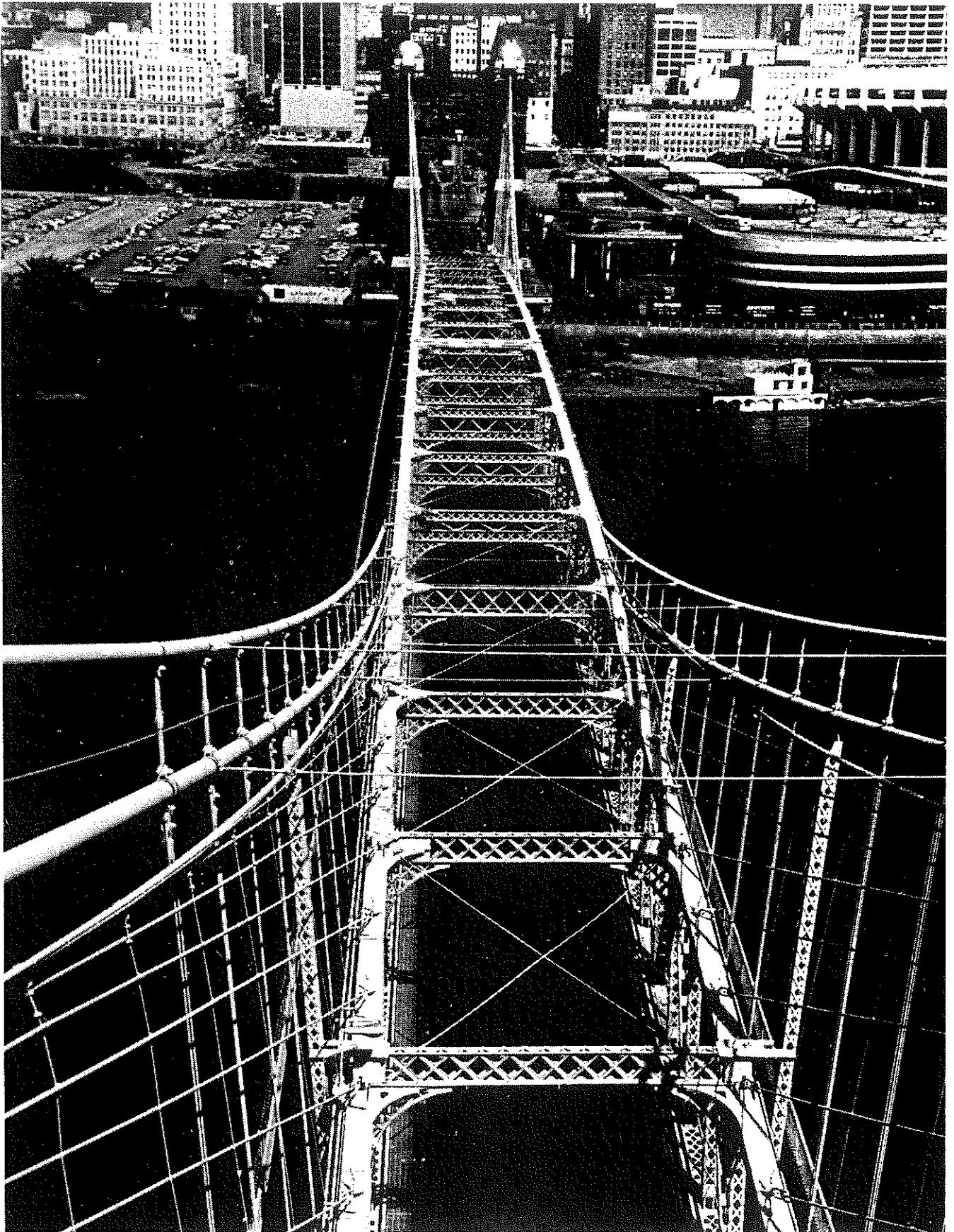


Figure 15. The Covington Bridge.



Figure 16. Water seepage from original upstream cable at midspan. Seepage is occurring at the splice point in the wrapping.

in the Kentucky downstream anchorage to three in the Kentucky upstream anchorage. Most of the broken wire ends had been painted, indicating these probably predate the present leakage problem. Unpainted broken ends of the wires showed severe general corrosion and loss-of-section near the fractures.

Many wires in the lower strands contain splices that presumably date to 1892. Most splices were located on the lower portion of the strands and were inaccessible. The splices were made by interlooping mating wire ends and wrapping each looped end to the parent wire with a tie wire (Figure 19). This type of splice does not provide high joint strength and was not the type of splice employed by Roebling on the wires of the main

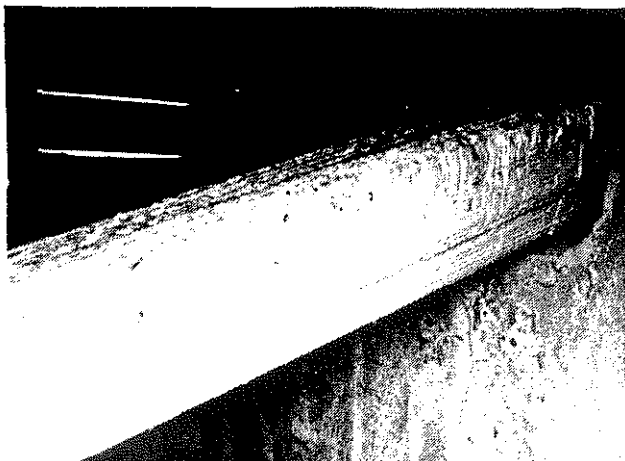


Figure 17. Pigeon droppings on a secondary cable, inside the Kentucky-tower turret.

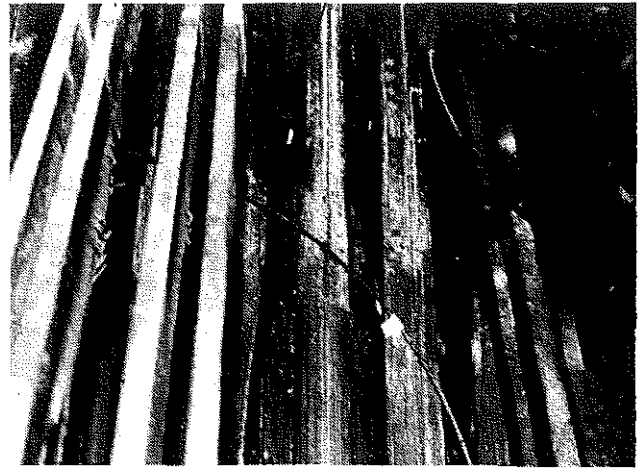


Figure 18. Deterioration to the strands due to roof leakage in the original anchor house.

cable (9). Since many of the spliced wires were loose, it is questionable whether those wires were bearing any load.

Besides roof leakage, moisture was observed on the strands adjacent to the splay saddle in the downstream Kentucky anchorage. That may be caused by leakage of water from the wrapped cable or by a sealing failure at the splay-saddle collar located outside the anchorage.

The Kentucky secondary anchorages were constructed as extensions of the original anchorages. The secondary cables entered those anchorages through the roofs. The strands and anchor assemblies employed the same paint system used on the original cables. Strands in the downstream, Kentucky secondary anchorage house were covered with a light dust. The upper surface of the strands were rough in a few locations, indicating possible presence of light rust under the paint. Excluding that observation, the paint and strands appeared to be in very good condition. A skylight was situated in the ceiling directly over the anchorage assembly. That was a make-shift installation, consisting of an old steel-framed glass



Figure 19. Wire splice in original cable anchor house.

window and a detour sign. However, there was no indication of water leakage on the strands.

The Ohio secondary cables were housed in separate anchorages located under the Ohio approach. The cables entered through large open portals in the headwalls of the anchorages. One unusual feature was the slight splaying of the cables before they entered the anchorages. The splayed portion of the cables was sheathed in a sheet-metal jacket that extended down to the splay saddles. The concrete, approach curbs were cast directly against the cable sheaths where cables crossed the curbs into anchorages.

The Ohio secondary anchorages were very dusty. At the time of inspection, the bridge trusses were being repainted and the large open cable portals allowed the sandblast refuse to enter the anchor houses. Pigeons had frequented the upstream anchor house, depositing bird droppings and feathers on the strands (Figure 20). The concrete approach roadway served as the roof for the anchorages. The ceilings in the anchorages, made of metal stay-in-place forms, had greenish stains and appeared to be corroding due to salting of the overhead roadway

(Figure 21). Some white residue was detected on the upper portions of several strands. This indicated some roof leakage may have taken place.

The strands and anchor assemblies were painted in the same manner as had been employed in the other anchorages. The paint appeared to be in good condition at most of the locations inspected. There was no sign of paint cracking or peeling; however, the upper surfaces of some strands were slightly rusted. This rust was detected under a heavy layer of black sandblast material that lay on the upper surfaces of the strands. Several strands were found to be rusted and swollen between the strands seizings in both anchorages (Figure 22). Those strands were connected to the lowest shoes on the anchor assemblies near the anchorage floor.

One break was found in the upper strands of the upstream anchor house, near the cable portal. Since the broken end had been painted, the cause of fracture could not be determined. One wire in the downstream anchorage ran between two adjacent strands. The wire was taut. Whether this was due to an impressed load or to tension caused by the seizings could not be determined. In

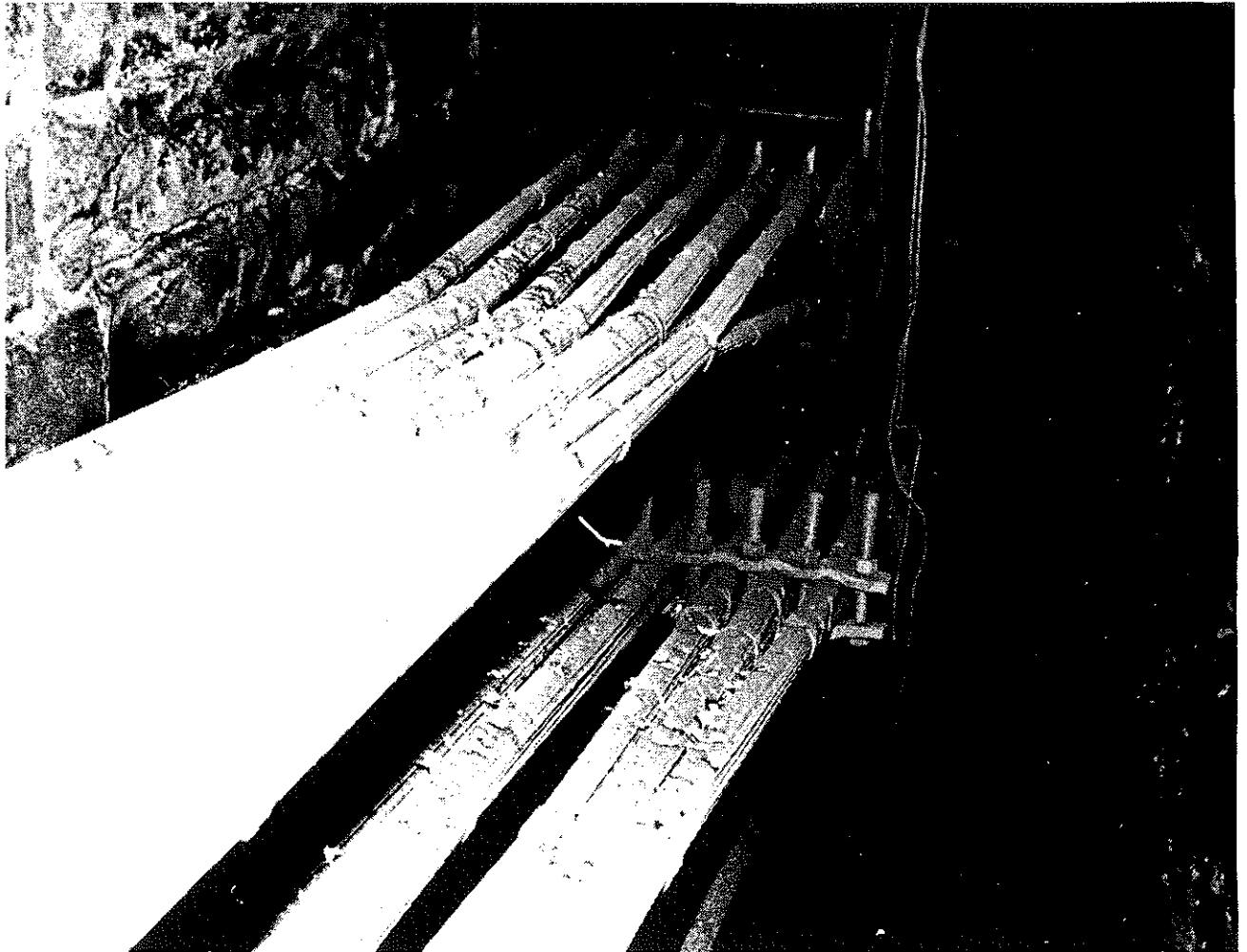


Figure 20. Cable strands in the upstream Ohio secondary anchor house. Note the pigeon pollution and sandblast refuse on the strands.

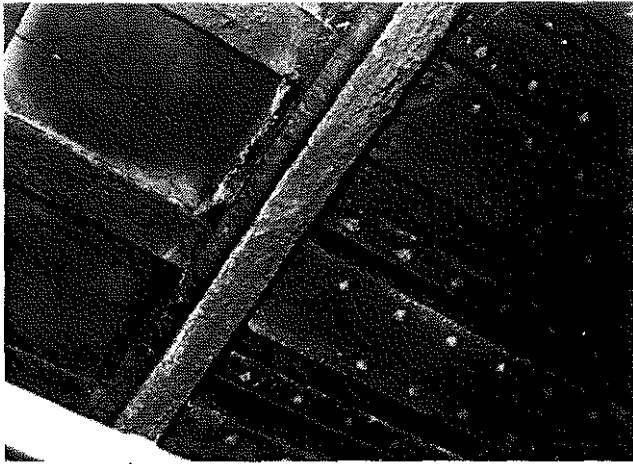


Figure 21. Stains on the ceiling of the upstream Ohio secondary anchor house.

either case, it was a sign of poor workmanship.

The Covington Bridge showed many signs of trespass. As with other Ohio River bridges in the Covington area, vagrants use the bridge as a private accommodation and toilet. Youths climb over the bridges for recreation. Graffiti has been carved into masonry of the anchor-house walls. Beer cans and whisky bottles were found in four anchor houses. Entry can be made into the Ohio secondary anchor houses by sliding down the cables through the large cable portals. It is possible that corrosion damage of the lower strands in the Ohio secondary anchorages was caused by persons urinating on the wires. Cyclone fencing guarding the Kentucky tower stairway had been pried open, and empty beer cans were strewn about the stairs and tower.

Activity of the pigeons is disconcerting. Pigeon droppings can expose workers to histoplasmosis. Pigeon dung combines with water to form acids, which in turn may cause corrosion cracking in the wires. A large quantity of pigeon dung is deposited on the cables at the tower roller supports. Those are points of high stress con-



Figure 22. Swollen strands in the downstream Ohio secondary anchor house.

centrations. Since the upper cables are unwrapped at the supports, the only cable protection is paint. The broken wire on the downstream secondary cable should provide sufficient warning as to the potential danger of that situation. Pigeon droppings are not as concentrated on the strands in the Ohio secondary anchorages. However, that is also of concern because the strands in the anchorages are only protected by primer coatings.

The secondary cables were designed to bear more than half the bridge loading. The cable wires are bare uncoated steel wires similar to those used in the first Portsmouth cables. The first Portsmouth wires failed by corrosion cracking after only 12 years of service. The steel wires on the Covington Bridge have been in service for 82 years.

While no major structural defects were observed on the Covington Bridge, problem areas were located that will require remedial action in the near future. The scope of this investigation was limited. More in-depth work is needed to ascertain whether corrosion problems exist in areas where physical access is limited, such as, the interior of the wrapped cables and under cable bands. Detection of seepage from the original cables makes inspection imperative in the next few years. While the wires in the original cables are made of wrought iron, they will still fracture if severely corroded. Such failures have been detected on the wrought-iron cables of the 130-year-old Wheeling Bridge (10).

A 72-hour traffic survey was conducted on the Covington Bridge during the period of October 6-9, 1980. Results are shown in Table 2. The daily traffic volume was 17,400 vehicles. Restriction of traffic on the Central Bridge will probably increase the loading on the Covington Bridge. Traffic was predominately light vehicles and buses. A Cincinnati bus-company terminal feeds directly onto the Ohio approach and is responsible for most bus traffic.

Table 2. Traffic Survey on the Covington Suspension Bridge (72 Hours) for Both Lanes.

Type of Vehicle	Count	Percentage
Autos and Pickups	47,553	91.14
Buses	3,595	6.89
SU-2A-4T	134	0.26
SU-2A-6T	605	1.16
SU-3A	62	0.12
SU-4A	0	0.00
C-3A	25	0.05
C-4A	34	0.07
C-5A	158	0.30
C-6A	2	0.01
Total	52,168	100.00

Note: Survey conducted between 1:00 pm on 10/6/80 and 1:00 pm on 10/9/80.

Conclusions

No major structural damage was detected on the cables of either Kentucky suspension bridge. However, it should be noted that the scope of the present work was limited, and additional examinations should be performed on both bridges to ensure their structural integrity. In the future, both bridges will require considerable maintenance to preserve their present structural soundness. Any maintenance work on the cables should be deferred until a better knowledge of the cable condition has been achieved.

Both Kentucky bridges have probably met, or exceeded, their anticipated service lives. The bridges have sufficiency ratings less than 50 (34.6 for the Covington Bridge and 20.6 for the Maysville Bridge), making them eligible for replacement under the FHWA Bridge Replacement and Rehabilitation Program (BRRP). The low ratings mainly are due to roadway dimensions and design load capacity -- not physical deterioration.

It would be impractical to modify the bridges to achieve passible sufficiency ratings (50+). Usually, this fact would make the bridges ineligible for rehabilitation using BRRP funds. However, there are mitigating circumstances favoring preservation of both bridges. The bridges have historical significance and are closely identified with the culture of their respective communities. This may allow use of BRRP funds to rehabilitate the bridges (11). Many older suspension bridges in the New York City area are being renovated using federal funds (12).

The Covington Bridge was the second bridge to span the Ohio River. It has been in use for 113 years and serves as a monument to the engineering genius of John A. Roebling, the noted suspension bridge builder. To the best knowledge, this is the oldest American bridge still in full active service. Owing to the fact that it is registered as historic property by the National Register of Historic Places, it would be extremely difficult to have such a prominent national landmark demolished. Therefore, as long as the bridge remains standing, some utility should be gained from it.

While the Maysville Bridge lacks the rich heritage of the Covington Bridge, it still has historical significance. It was one of the first suspension bridges ever built employing structural strand. Its stark functionalism is typical of many successive bridges built during the era of the late 1920's and 1930's. That period is oftimes referred to as the "Golden Era" of bridges. Due to its many innovations, the Maysville Bridge can be considered a prototype of a genre of economical short-span suspension bridges. It is an outstanding example of this type of structure. The bridge is a strongly-identified local landmark. It is replicated on the Maysville logo. At this time, several communities between Maysville and Ashland are requesting erection of new bridges over the Ohio River. If all requested bridges are constructed, a capital outlay of over

100 million dollars will be required. It would be difficult to justify demolishing an old yet functional structure whose continued existence would offset some very expensive construction desired in this region.

Some comments are required about past maintenance on the suspension bridges that will serve as a framework for the subsequent recommendations. Unfortunately, both suspension bridges have been subject to neglect. Maintenance has been performed on them only when absolutely necessary and, then, only when a problem had manifested itself on a large scale and was expensive to correct. For instance, the bridges have been painted only when paint chipping and rust were visible on many parts of the structure, requiring that the entire bridge be painted by contract. Poor housekeeping in the anchorages of both bridges indicates proper routine maintenance is lacking.

Most potential problems and early signs of deterioration on large bridges are usually detected during annual inspections performed by the Division of Bridge Maintenance. The 1977 report of annual joint inspection of the Covington Bridge is a good example of this work (13). The report was written by B. Compton of the Division of Bridge Maintenance. The report mentioned loose (broken) wires in the anchorages, strand swelling due to corrosion, the pigeon problem in the towers, and rust stains around the exterior portion of the splay saddles (which the present inspection overlooked). Some of the anchorage wire problems have been known for many years. The roof leakage may have occurred some time after the 1977 report. If so, its deleterious action is more aggressive than originally presumed. There were no signs that action was taken to cure the cable-related problems enumerated in the 1977 report.

While indications of impending problems of the Kentucky suspension bridges are not as dramatic as finding a large number of broken wires, the need for immediate action is as great. Discovery of major defects in the cables of either bridge is not anticipated; however, this work is necessary to ensure safety of the public. At the time of closure, the Portsmouth Bridge was, in the author's opinion, in a structurally critical condition. That was not determined until some six months after the bridge was closed when the cable bands were removed. The Ohio Department of Transportation acted promptly and correctly in closing the structure at the first signs of increasing structural decay. However, KYDOT would be remiss in allowing either Kentucky suspension bridge to deteriorate to a similar structural state as that of the Portsmouth Bridge prior to its closure.

A final comment should be made, related to both corrosion and trespass problems. The words of D. B. Steinman (14) are particularly apt, "The safety of a suspension bridge depends on the security of its anchorage."

Recommendations

1. Comprehensive inspections should be performed on the interior portions of cables on the Covington and Maysville Bridges. Work on the Maysville Bridge should have priority over the Covington Bridge.

(a) Inspections should include the main cables on both side spans and the main span. Each cable should be inspected by unwrapping at least four different locations for an entire panel length. Interior inspection can be performed by wedging (wood, brass, or plastic wedges) the strands apart.

(b) At least four cable bands per bridge should be removed for inspection of the underlying wires. This will require fabrication of a lifting jig to eliminate the dead load from the bands prior to removing the suspender cables and disassembling the bands.

(c) Unwrapped panels may be rewrapped with a neoprene-chlorinated rubber paint wrapping of the "USS ELASTRO-WRAP SYSTEM" type employed by the American Bridge Division of the U. S. Steel Corporation. This work should be scheduled so completion will be no later than a September to allow proper curing of the wrapping material.

(d) Suggested locations for wrapping and band removal could be provided by the Transportation Research Program. Manpower requirements may necessitate the work be performed by contract. Four consulting firms -- Howard, Tammen & Bergendoff; Modjeski and Masters; Steinman, Boyton, Gronquist & Birdsall; and Amann and Whitney -- have suspension bridge experience necessary to perform inspections.

2. Install 16 inspection ports on the main cables of the Covington Bridge. One port should be installed per cable on all the side spans and on opposing shallow inclines of the main span. A comprehensive cable inspection using a lift-boom should precede this work. The lift-boom would allow inspectors to locate points where problems may be expected, such as locations that have rust stains or disturbed wrapping. Cables should be cleared of bird dung at the towers. Paint should be removed from the outer strands, which are unwrapped at those locations. The exposed wires should be thoroughly inspected for cracks. The cables then could be repainted with a chlorinated-rubber paint.

It would be desirable to perform a comprehensive inspection of the Covington Bridge approximately one year after inspection ports are installed.

3. Modifications should be made on both bridges to prevent corrosive attack in the anchor houses and to promote good housekeeping.

(a) The Maysville Bridge anchorages should be equipped with lockable doors installed at ground level to provide entrance to the anchor houses. If flooding is possible at ground level, watertight doors should be used. Existing sidewalk entrances should be sealed.

Lighting and electrical outlets should be placed in the anchor houses. Anchor houses should be thoroughly cleaned. All exterior windows should be permanently sealed. Floor drains should be cleared. Interior walls and floors of the anchor houses should be painted a light off-white color. Strands and anchor assemblies should be cleaned and repainted with a chlorinated-rubber paint. The mouth of each sleeve bushing should be sealed with a zinc-impregnated grease where the strand end enters the anchor socket assembly. Electrical dehumidifying and dust-eliminating devices should also be considered for installation if problems with humidity and corrosion persist.

(b) The roofs of the original Covington Bridge anchorages should be sealed to eliminate water seepage on the strands. If necessary, simple covers should be placed over the strands and anchor assemblies to prevent direct impingement of water. All anchor houses should be thoroughly cleaned. Walls of the anchorages should be painted a light off-white color. Cable entrance portals on the Ohio secondary anchorages should be permanently sealed. Strands and anchor assemblies should be cleaned and painted with chlorinated-rubber paint. Permanent ladders should be installed on all anchorages (this may involve extensive masonry work on the Kentucky secondary upstream anchor house). Doors to all anchorages should be fitted with weatherstripping. All doors should be fixed to function properly. Locks should be used on each entrance. Each anchorage should be fitted with electrical lights and outlets. Electrical dehumidifying and dust-eliminating devices should be installed in the anchorage houses. The ceilings of the Ohio secondary anchorages need to be sealed to prevent leakage of salt water onto the strands.

(c) Cable handrails should be installed on both cables of the Covington Bridge to facilitate exterior inspection.

(d) Pigeon droppings should be cleaned from secondary cables at the towers. Cables should be repainted at the towers with a chlorinated-rubber paint. Heavier screens or perforated steel plating, cut to a good fit, should be installed. Consideration should be given to installing sonic bird-repelling devices, such as the "ULTRASON ET" manufactured by the BIRD-X Corporation of Chicago, Illinois.

4. An effort should be made to stop unauthorized trespass on the bridges. This may require enclosing walkways with chain-link cages. Lockable intruder guards should be placed on access ladders. Law-enforcement officials should be persuaded to deter vagrants and juveniles from frequenting unauthorized portions of the bridges. This may be aided by placing microwave or ultrasonic intruder alarms on key locations of the bridges. The alarms could be tied into remote police monitors or to

audible alarms located near points of intrusion. The prevention of frequent vandalism to bridge lighting systems would justify this effort.

5. The Maysville Bridge cables will eventually need renovation to increase corrosion resistance. Four approaches to this problem have been considered: (1) inject an inhibitor-impregnated plastic into the interstices of the cables and rewrap with the conventional wire-paint system; (2) install covers over the cables; (3) rewrap the cables with a neoprene-chlorinated-rubber paint wrapping system; (4) cover existing wrapping with a high-build chlorinated-rubber paint. One of the last three proposals may also be used in conjunction with the first proposal. Expected cost of such work is about two million dollars. If cables of the Covington Bridge show significant deterioration, similar work may be required.

6. An effort should be made to alter traffic flow on the bridges, especially during periods of peak usage. Relocation of the bus terminal on the Ohio approach of the Covington Bridge probably precludes limiting the bridge only to cars; however, it would be desirable to ex-

clude all truck traffic from the bridge. The Covington Bridge is a functional landmark, but its use should be restricted. Theoretically, cables of the Maysville Bridge are more than satisfactory to handle present loads. However, the truss may be slightly over-extended by infrequent heavy loads (15). If impending internal inspection reveals no defects, with the projected renovation, the bridge may probably remain in service for another 50 years. The situation may warrant building another bridge in the Maysville area. A two-lane bridge could be constructed to bypass the commercial district of Maysville. Then, the suspension bridge could be retained for urban traffic between Maysville and Aberdeen, Ohio. Continuous right-turn lanes at the end of each approach would greatly aid in reducing congested traffic that accumulates on the bridge during peak-use periods.

7. Steps should be taken to ensure faster implementation of maintenance work suggested by the annual inspection reports. This is especially true of defects related to suspension bridge cables.

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