Corrosion of Highway Structures by Acid-Bearing Drainage Water in Hopkins County

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MEMO TO: W. J. Crouse  
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At the time of the Highway Conference in April, Mr. Hopgood discussed with me the corrosive action of acid waters on concrete and corrugated metal structures in Hopkins County, and recently he requested any advice or recommendations we may have for restoration where the structure has been severely damaged. The attached memo report by J. H. Havens, who has conducted our acid water studies, offers several suggestions.

In the case of the concrete piers, the concrete encasement diagrammed in Fig. 6 appears to be most practical. You will note that Mr. Havens suggests a bituminous-coated metal form for more protection, and that is directly in line with the suggestion made during the conference in Frankfort, June 18, when the asbestos-bonded sheets with turned edges for bolting on the inside were discussed. Obviously, any arrangement with a bituminous-coated surface in contact with the acid water should have the longest life provided the bituminous coating adheres.

For treatment of the multiplate arches that have corroded, it should be possible to apply a light bituminous coating with a good possibility for it to remain intact where it is not exposed to sunlight nor to debris that could abrade the coating in time. If one of these coatings has worked successfully on liner plates in mine acid waters it should certainly protect the metal in the presence of this water with a lower acid concentration.

When Mr. Hopgood has reached a decision on something he wishes to try in these locations, we will be glad to cooperate in the keeping of records on application and performance if you wish.

L. E. Gregg  
Assistant Director of Research
MEMO TO:  L. E. Gregg  
Assistant Director of Research

SUBJECT: Corrosion of Highway Structures by Acid-Bearing Drainage Water in Hopkins County

Pursuant to your conversation with Mr. Hopgood concerning the above matter, Mr. Peed and I contacted Mr. Charlie Rogers, Resident Engineer, Madisonville, and made an inspection of the locations in question. In specific connection with this, you will recall from our Progress Report No. 1 on "A Survey of Acidity in Drainage Waters and the Condition of Highway Drainage Installations" that the acid conditions in Hopkins County were rated as extremely severe, if not the most critical in the state. It was, in part, due to the prevailing severity there that led to the selection of a location at Mortons Gap for our test installation (See page 37 of the report).

As a matter of record in further connection with the test installation, a heavy rain (3 1/2 in. occurring on or about April 15) dislodged and silted over most of the test sections of pipe. On April 29, at the time of our inspection with Mr. Rogers, local maintenance forces obligingly made the necessary restorations.

In the course of our inspection trip, Mr. Rogers pointed out numerous instances of serious damage to small drainage structures.
Several of these were typical of conditions described in our Progress Report, and were more-or-less incidental to the inspection of two major structures and several multi-plate arch culverts.

**Nortonville Over-Pass, U.S. 41** - The first photograph, Fig. 1, was taken from the eastern side and looking westwardly. It shows the position of two of the piers within the stream bed. The second photo, Fig. 2, is a close-up of the pier in the foreground and shows severe corrosion at the water line. Extensive mining operations are in progress about one mile upstream, looking westwardly into the photograph. The channel of the stream is highly silted, and the water appeared to be about 12 in. deep around the pier. A sample of the water, taken at the time of the inspection was tested in the laboratory and found to be severely acid. Estimating in terms of the sulfuric acid equivalent of conductometric tests, the acid content would be about 0.35 gram per 1000 cc, or 350 parts per million, estimated pH 3.0 to 3.5.

This structure was built in 1938, and it is assumed that the corrosive agents have been active throughout the interim period.

As may be seen from Fig. 3, the western pier was only partly exposed to direct contact with the corrosive water. In consideration of this fact, an examination of the conditions at this pier, by shallow excavation, was made on June 18, by laboratory personnel; and it was found that no corrosion has occurred on those sides of the pier now insulated by earth-fill. These findings suggest a very practical means of insulating both piers from further corrosion. The damaged piers could be repaired, coated heavily with bituminous material (See section on protective coatings) as an additional precaution, and insulated with about 24" of a high clay
Fig. 1: Nortonville Overpass, U.S. H1, looking westwardly. This photograph shows the position of the piers with respect to the stream channel.

Fig. 2: Close-up view of pier in the foreground of Fig. 1, showing severe corrosion at the water line.
Fig. 3: Photograph showing soil insulation on shore-sides of western pier. Severe corrosion is apparent where the pier is in direct contact with the water.

Fig. 4: Diagram illustrating the conditions expected below the water line.
soil. It is recognized, however, that complications might arise by constraining the stream and that it would be necessary to provide a retaining wall of some kind to hold the fill in place. Since such a wall would not be connected to the structure in any way, concrete could be used and permitted to corrode under the possibility of having to replace it at some future date, 30 or 40 years hence. Fig. 5 is intended to illustrate the general idea.

The merits of an earth-fill, of course, lie in the fact that the soil water surrounding the piers would be comparatively static and would be neutralized by the concrete. That would mean, also, that some corrosion would have to take place, but it would be of minor consequence in comparison to the present rate of corrosion. The addition of a bituminous seal between the pier and soil would reduce that possibility even further, and the earth-fill would afford considerable protection for the bituminous material against abrasion and weathering.

In repairing the damaged sections of the piers, every effort should be made to remove all of the softened concrete and to determine whether the reinforcing steel has sustained any damage. It is not anticipated the damage has progressed that far or that replacement of the concrete itself will require any special technique.

With more specific reference to the existing damage to the piers, your attention is called to discussions on the corrosion of concrete appearing on page 8 and page viii, Appendix A, of Progress Report 1, where consideration was given to the loss in strength accompanying exposure to
Fig. 5: This sketch is intended to illustrate the use of earth-fill insulation and a retaining wall. Actually the fill should slope from the crest of the bank at the left to the retaining wall to prevent water from standing around the piers.
corrosive water. The possibility is suggested that serious loss of strength may have taken place within the interior of the pier due to losses of lime \((\text{CaO})\) from the cement. It seems, however, that damage of this type is usually more extensive if the concrete is very porous. Obviously, the more porous the concrete the greater the likelihood that corrosive waters may infiltrate to the inner-most depths. In the case of dense, non-porous, concrete, the corrosion is confined more at the surface, and the extent of damage is apparent from visual inspection. With this possibility in mind, it might be worthwhile to examine these piers by non-destructive methods such as modulus of elasticity determinations from wave-velocity measurements, i.e. Soniscope.

Another possibility for correcting the condition would be to chip away the soft concrete and then pour an encasement of reinforced concrete about 14 in. thick around the piers as illustrated in Fig. 6. There would be a calculated risk involved in this method also, but it would be taken into account in the thickness of the encasement. The method would simply be a means of removing the corrosive zone farther from the uniform section of the pier. Based on the rate of corrosion during the past 14 years, it is estimated that 14 ins. of insulating concrete would afford maintenance-free protection for at least 60 years which would probably exceed the useful life of the structure. This method would not constrict the stream appreciably and it would be applicable to off-shore piers.

Since it will be necessary to install caissons or dams in order to repair the pier itself, the additional forms and temporary footings for the encasement could probably be placed at very little extra expense. The encasement, however, should extend about 2 ft. below the corrosive
Cut Horizontal Bench

Horizontal Bars are U-Shaped and Spaced at 9" on Centers.

Vertical Bars are 5/8" Straight and Placed as Shown.

Slope 1 in 12

Water Line

Stream Bed

14" Clear Center to Center

24" Lap

2" Chamfer Around Top and Down Sides

Fig. 6: Diagram illustrating protective concrete encasement around corrosive zone of pier.
zone and about 2 ft. above the normal water-level. Those heights and depths are based entirely on personal judgement and are believed to be adequate for those particular conditions.

As a further precaution, the concrete could be sealed with a bituminous coating which could be extended to any desired distance above and below the encasement.

A more simple modification of this method could possibly be effected by using bituminous coated metal pipe sections for the forms, which would be left in place. Abrasion and weathering would eventually expose the metal corrosion, but there would still remain several inches of concrete insulation. This would mean too that the encasement would be circular rather than square or rectangular unless special forms were fabricated.

The possibility of using hard-burned or vitrified clay tile sheathing over the corrosive zone has also been considered (See Fig. 7), but there seems to be some insurmountable difficulties involved. The method would produce a very neat job insofar as appearance is concerned. The first difficulty arises from the availability of the tile sections, and the second arises from the necessity for using steel bands, or some similar means, to hold the facing tile in place. A bituminous cement seal under the tile would, of course, tend to hold them, but there is no positive assurance that the cement alone would be adequate. Steel bands, however, could be coated with bitumen and preserved fairly well. Also, tile sheathing like this would be quite vulnerable to fracture by debris carried in the stream. The most significant advantages in this
Fig. 7: Diagram illustrating method for sealing pier by use of bituminous cement and tile sheathing.
method lies in the fact it does not require massive additions to the structure and the comparative ease with which the sheathing could be placed, and even the possibility of using cold-applied mastic joint filler as the bituminous seal.

It is recognized that the choice of methods is limited in a practical way to one involving readily available materials. For that reason, I believe that encasement in concrete using either removable or bituminous coated metal forms would provide the most satisfactory solution to the problem.

**MP 54-680-2, Rural Secondary, White Plains to Mortons Gap** - This structure, shown in Fig. 8, was completed last year and is already beginning to show obvious corrosion in much the same manner as found at the Nortonville overpass. I believe that the piers here are wide-flanged H-piles with concrete encasements. A sample of the water, taken April 29, tested very acid but only about one-half as concentrated as the water tested at Nortonville. It is rather interesting to note that the stream at Nortonville, Pleasant Run, is an upstream tributary of Drakes Creek which this structure bridges. The flow here appeared to be much more rapid, which would naturally be expected to accelerate its corrosive action.

Fig. 9 shows a close-up view of the pier in the left foreground of Fig. 8. The material disintegration here has not yet produced severe cavitation in the uniform section of the pier but, in five or six years, the conditions here could be even more critical than those now existing at the Nortonville piers.

In considering corrective measures for these piers, I see no reason why the same method selected for use at the Nortonville location
Fig. 8: MP 54-680-2, Bridge crossing Drakes Creek, White Plains to Mortons Gap Road. This photograph was taken from the upstream side of the structure.

Fig. 9: Close-up view of piers in left foreground of Fig. 8, showing very early corrosion at the water line.
would not prove equally effective here. There are, however, ten piers here that are now in direct contact with the water. Also, a flash flood might conceivably shift the channel to a different span. That would be a rather remote possibility but it should be considered.

Although I can't see any particular advantage to a single enclosure surrounding each bent, it might prove more economical than trying to encase each pile individually.

Multiplate Arch Culverts With Sandstone Masonry Headwalls, Mortons Gap to White City - The conditions observed as well as the problems involved in correcting the condition are evident from Figs. 10 & 11. Mr. Rogers indicated that these culverts were installed by the W.P.A. about 1935 or 1937. The corrosive zones are, of course, those most frequently in contact with acidic waters. Apparently, the channel in which the base of the arch rests was not sealed with bitumen at the time of installation and consequently, it remains filled after high-waters have subsided. That in itself, is conducive to corrosion even with less acidic waters.

The possibility that corrosion has taken place on the inside surface leaving a thin shell on the exterior side could probably be tested by sounding with a hammer. Soundings along the corrosive zones might also indicate whether or not structural restorations would have to be made. If the arch is structurally adequate in the corroded zone, the metal could be cleaned by sand-blasting and sealed with bitumen (See section on protective coatings). If structural restoration is necessary, the addition of bituminous coated reinforcing plates as illustrated in Fig. 12 is suggested
Fig. 10: Corroded multiplate arch culvert, installed about 1937, Hortons Gap to White City road.

Fig. 11: Corroded multiplate arch culvert located on Hortons Gap - White City Road, installed about 1937.
as a possibility. At least the idea seems practical from the standpoint of not having to replace the entire culvert. Bolt-heads for the vertical joints would have to be cut off so the reinforcing plates could be jacked into place. The plates could extend as high as the bolt-heads of the horizontal joint. In order to tie the plates into the existing structure, tie-bolts such as shown in Fig. 13, could be threaded through corrugations as illustrated in the diagram since access cannot be made to the inside. The holes would probably have to be drilled after the plates were jacked into place.

Some difficulty might be encountered in obtaining plates having the same corrugations and radius. Some of the commercial fabricators however, may already have such a method for bolting joints together in cases where access is limited.

Once the plates were bolted in place, all joints and bolts should be coated and sealed. I do not believe that the concrete footings will require any restoration or treatment other than a heavy application of bitumen.

About the only alternate would be to fabricate a new bituminous coated arch 2 or 3 inches shorter in radius inside the existing arch and then grout between the old arch and the new one. As a matter of fact, this would probably be the most satisfactory and economical method in the long-run if the structure is in danger of failure. Either method would avoid any disturbance of the fill or head-walls.

Protective Coatings - There are several recent developments in protective coatings, such as plastics, resins, and bitumens for use on concrete and metal. Plastic linings, for concrete sewer pipe, both spray coated and prefabricated, have been reported as successful on a few major
Fig. 12: Visualized appearance of restored multiplate arch with reinforcing plates in place.

Fig. 13: Diagram illustrating a possible method for bolting reinforcing plates to an existing multiplate structure.
projects. I believe the Pennsylvania Highway Department requires that concrete drainage pipe installed in corrosive areas be lined with terra cotta or vitrified clay. Bituminous coatings are effective provided they have adequate thickness and bonding characteristics.

Factory coatings of bitumen on metal are, of course, applied under precisely controlled conditions. In impromptu coatings such as would be required for these structures, some difficulty is encountered in the use of hot-applied material due to the fact that the structure conducts the heat away and hardens the bitumen before adequate bond can be formed. Cut-back asphalts or lighter bitumen will not harden sufficiently to support adequate thickness without flowing. A possible solution to this problem would be to prime the surfaces with a cut-back material over which a harder hot-applied bituminous cement could be brushed to build up the desired thickness. It is my understanding that the Trumbull Asphalt Company of Chicago has a cold-applied material which has shown promising performance as a protective coating for metal liner plates used in mines. Unfortunately, we do not have specific information about this and some other materials which have promise. Letters of inquiry have been written, and we should have some samples for test soon.

Future Construction - I believe that it would be within the realm of practicality to recommend here that these or similar protective provisions be incorporated into the design and construction of future bridges, particularly, where the water is known to be corrosive.

James H. Havens
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