Michigan Galvanized Metal Culvert Corrosion Study

R. W. Noyce and J. M. Ritchie, Testing and Research Division, Michigan Department of Transportation

A systematic evaluation of corrosion in galvanized metal pipe culverts throughout the state of Michigan was undertaken. Over 1900 culverts were field inspected and visually rated. More than 200 of these sites were selected for a detailed analysis that included determining soil and surface-water resistivity, soil and surface-water pH, soil chloride and sulfate concentrations, corrosion current, natural soil texture, drainage characteristics, and water-table depths. Results showed significant corrosive attack in 139 culverts. Resistivity is not a predictor of corrosion rate but rather an indicator of potentially corrosive environments. Soil and water pH values did not relate directly to culvert condition. The polarization corrosion current measured in the laboratory was the most significant corrosion predictor of all the parameters studied.

Soil conditions, strength requirements, and hydraulic characteristics have traditionally been the main criteria for selecting culvert materials on roadway projects. The lack of long-term quantitative information regarding the durability of specific materials in varied environments has prevented judgments based on service-life expectancies. This has often resulted in frequent periodic maintenance and replacement of corrosion-deteriorated culverts at high maintenance expenditures.

The importance of considering durability when selecting culvert materials came to the forefront in Michigan during the spring of 1972. Severe deterioration of a 9½-year-old galvanized corrugated metal pipe (CMP) culvert, which caused a roadway shoulder on I-75 in Mackinac County to collapse, prompted a study of a 90-km (56-mile) section of I-75 in Mackinac and Chippewa Counties (1).

In that study, 290 galvanized culverts that had an average service life of 11 years were evaluated, and it was found that 14 percent had undergone serious localized deterioration. Even though the area was intensively investigated, the relationships between the apparent causes of corrosion could not be determined. However, it was observed that the major deterioration was occurring from the exterior and that the soil acted as the corrosion-controlling factor. Low resistivity, presence of chlorides and sulfates, nonuniformity of soil backfill, differential aeration, soil moisture differentials, presence of organic materials, and sulfate-reducing bacteria were major factors associated with the rapidly deteriorating culverts.

It became apparent that a new statewide policy for selection of culvert materials should be developed and that it should not be based solely on the data obtained from this limited geographical area. Therefore, a statewide investigation was undertaken to determine whether (a) culvert corrosion is a serious statewide problem, (b) corrosive sites can be accurately identified, and (c) the state can be zoned into areas in which metal culverts should not be used.

STUDY APPROACH

A systematic evaluation of galvanized CMP culvert corrosion throughout the state was accomplished in a two-phase program. In the reconnaissance phase (phase 1) an inventory, performance assessment, and service history were provided by district personnel who located and visually inspected about 200 culverts in each of the state's nine districts. Phase 2 was oriented toward identifying aggressive conditions and developing potential corrosion-detection methods. To ensure uniformity of inspection, a standard reporting method developed for the previous I-75 study was used to collect all data.

The first four sections of the inspection form (Figure 1) were completed in phase 1. Culvert interiors were given a thorough visual examination and sounded with a sharp metal probe at selected intervals. Pipe exteriors were exposed at their end sections and visually inspected. A rating was then assigned to individual culvert regions. These ratings describe the worst condition found in that region and are representative of the degree of corrosion in each pipe.

Approximately 1920 CMP culverts that had an average service life of 12.2 years were inspected during phase 1. Of these, 139 had deep pitting (25 rating) or perforations (0 rating) or both. While neither necessarily constitutes a structural failure, both do indicate serious deterioration through corrosion and signal an impending failure.

The phase 1 study indicated that rapid deterioration of some galvanized CMP culverts by corrosion is being experienced in every district throughout the state. Based on this and the need to develop criteria to classify the aggressiveness of corrosion at proposed culvert sites, phase 2 was initiated.

Phase 2 was an intensive study of a few selected culvert sites by Geotechnical Services Unit personnel. This phase, which consisted primarily of field and laboratory testing of corrosive parameters, was oriented toward identifying indicators of corrosion and outlining areas where a high incidence of corrosion could be expected. Sites for in-depth study were generally chosen on the basis of

1. Culverts with a known service history of 10-15 years,
2. Culverts with valid ratings in all portions,
3. All culverts rated 0 and 25,
4. A minimum of 30 culverts in each of the 50, 75, and 90 rating classes for the entire state,
5. Geographic location,
6. Environmental conditions,
7. Accessibility to culvert interior for a detailed inspection, and
8. Culverts of between 12 and 16 gauge.

To the list of culverts selected by these criteria, a few culverts with very short service times (3-4 years) and a few with up to 40 years' service were added.

Buried metal drainage structures are subject to corrosive deterioration from both the interior and exterior. Our previous studies employed a wide variety of tests to evaluate both the surface-water and the soil environments, which is the normal approach used by other corrosion investigators (1-4). However, experience indicates that, in Michigan, the major deterioration occurs from the culvert exterior and that the soil and soil moisture factors control the corrosion.

Very few of the surface-water test results showed a significant relation between water and corrosion. Consequently, the basic test program was modified for this study. Although it was oriented toward fully assessing

Figure 1. Standard inspection form.

State ____________ County ____________ Road ____________
Control Section ____________ Location by Station or Speedometer ____________
Date of Inspection ________ Photos ________ By ____________

Riveted ____ Plain Galv. ____ Dia. ____ Length ____ Date Installed ________
Helical ____ Other ____ Wall Thickness ____ Slope ____ Yrs of Serv. to Date ____
Struct. Plate ________

Nature of Watershed - (City)(Country)(Swamp)(Forested)(Tilled)(Pasture) Other ________
Flow (Constant)(Occasional)(Stagnant)(Scouring)(Filling)
Other ________ Est. Rate ________ ft/sec. Direction ________
Stream Bed Load ________ (Abrasive)(Nonabrasive) Culvert Bed Mat. ________
Erosion ________ (Yes)(No) High Water Line ________

Soil Series ____________
Comments ____________

Visual Evaluation

Rating Comments	Visual Rating Scale
Top ____________	90 Galvanizing intact
Sides ____________	75 Galvanizing partly gone, some rust
Invert ____________	50 Galvanizing gone, significant metal loss
Pipe Exterior ____________	25 Deep pitting, heavy metal loss, metal can be perforated with a sharp metal probe
	0 Metal perforated

Field Measurements

Water pH ____ Min. Soil Resistivity (1) ____ Ohm-Cm Location ________
Soil pH ____ (2) ____ Ohm-Cm Location ________
Self Potential ________ (3) ____ Ohm-Cm Location ________
Culvert to Natural Soil Potential ________ Water Resistivity ________ Ohm-Cm
Culvert to Backfill Potential ________ Backfill to Natural Soil Potential ________
In-place Soil Resistivity (1) ____ Ohm-Cm Depth ____ Location ________
(2) ____ Ohm-Cm Depth ____ Location ________
(3) ____ Ohm-Cm Depth ____ Location ________

Field Samples

Surface Water ____ Location ________ Soil (1) ____ Location ________
Soil (2) ____ Location ________
Soil (3) ____ Location ________
Culvert Specimen ________

the soil environment, the program also included water evaluations that could be accomplished within a reasonable time by using readily available equipment. Where field evaluations indicated that major corrosion was occurring inside a culvert or that surface water was possibly controlling the corrosion, additional water testing was conducted.

In-place resistivity soundings were made in the natural soils at each end of every tested culvert (5). Values were determined for soil layers in immediate contact with the culvert to a depth of about 1.2 m (4 ft) below the invert. The area of lowest resistivity, which reflects the most corrosive condition, was selected for sampling and further testing. The percentage of natural soil moisture, as well as electrolyte contents, is known to affect field-measured in-place resistivity (6). This in situ soil moisture content is subject to seasonal fluctuations that should be recognized in relating resistivity to corrosion.

A minimum soil resistivity was obtained by placing the sampled soil in a soil resistance box and measuring the specific conductance with a conductivity bridge by adding distilled water incrementally to the soil. These minimum values provide a common base for analysis and comparison.

Spontaneous potentials were monitored during in-place resistivity soundings. Anomalous readings signal the presence of stray electrical currents caused either by manmade mechanisms or by naturally occurring phenomena. Spurious currents, regardless of their origin, are known to cause rapid metal deterioration.

Because acidity and alkalinity are also parameters commonly used to describe the aggressiveness of the natural environment, hydrogen ion concentration (pH) values were determined at each site for both the soil and the surface water. Chloride and sulfate ion concentrations for soil samples were also determined at each site by using standard soil extract methods (7). When field conditions indicated the necessity of water testing, surface-water samples were obtained at the inlet end of the culvert.

Culvert metal samples were obtained where possible to determine characteristic corrosion forms and products. Further, laboratory polarization tests, to estimate corrosion current, were conducted on soil samples taken at 239 culvert sites (8, 9).

Table 1. Comparison of corrosion occurrence per rating class for minimum soil and surface-water resistivities.

Corrosive Classification	Resistivity Range (Ω·m)	No. of Occurrences in Soil Resistivity Test						No. of Occurrences in Surface-Water Resistivity Test					
		Rating Class						Rating Class					
		0	25	50	75	90	Combined	0	25	50	75	90	Combined
Severe	0-20.00	17	13	18	9	4	61	12	2	8	2	6	30
Heavy	20.01-45.00	14	32	20	10	14	90	6	6	2	3	2	19
Mild	45.01-60.00	4	4	6	3	6	23	2	1	1	0	0	4
Little or none	>60.00	6	10	15	12	9	52	6	3	8	2	0	19
Total		41	59	59	34	33	226	26	12	19	7	8	72

STUDY FINDINGS

Of the 418 galvanized culverts visually examined during the phase 2 study, 226 were selected for intensive study. At inspection, the culverts varied in age from 4 to approximately 40 years. Three basic culvert types were encountered: circular corrugated metal pipes, corrugated metal arch pipes, and corrugated structural plate culverts. All were fabricated from a copper-steel base metal galvanized on both sides by the hot-dip process, in which a surface coating of not less than 0.7 g/cm^2 (2 oz/ft^2) is deposed. All but two of the structures were plain galvanized. One of the two exceptions was bituminous coated and paved, while the other was asbestos bonded and bituminous coated. In terms of original thickness, the gauge of all the pipes ranged from 8 to 16.

Culverts selected for intensive study were distributed throughout the state. In total, 42 of Michigan's 83 counties were included in the intensive study. Approximately 23 geologic and soil-texture classifications were included in the analysis.

General observations from field evaluations indicate that the pipe extremities [first 1.2-1.8 m (4-6 ft)] tend to deteriorate at a faster rate than the middle portions. Although some corrosion is taking place on the insides of the culverts, in most cases the major deterioration is occurring on the exterior, where the soil is the corrosive agent. Severe interior corrosion was apparent in only three culverts, for which tests confirmed that the surface water was the aggressive agent.

Two of the culverts inspected during phase 2 were not plain galvanized. One bituminous-coated and paved culvert was nine years old at the time of inspection. The bituminous coating was absent from the culvert interior between the 3:00-5:30 and 6:30-9:00 positions and had lost its adhesion in most other areas. Where the culvert metal was exposed, it had undergone a significant metal loss (50 rated). Examination of the exterior bituminous coating revealed that, in areas that were protected by granular backfill and that lay above the water table, the coating retained its integrity. An asbestos-bonded and bituminous-coated pipe nine years old was also evaluated. Portions of this culvert's invert had suffered serious deterioration and heavy metal loss and could be perforated by a sharp metal probe (25 rated). The pipe's exterior had also lost some of its galvanizing (75 rated).

These two additionally protected culverts were compared with nearby plain galvanized CMP culverts installed in similar environments. This evaluation did not indicate that a significant increase in corrosion protection was obtained by using these coatings.

Minimum soil resistivity measurements varied from 4.33 to 346.94 Ω · m. The relationship of resistivity ranges to culvert condition is shown in Table 1. There is an obvious trend for the more severely deteriorated culverts (0 and 25 rated) to occur in lower-resistivity soils (0-45 Ω · m). This demonstrates that low-resistivity soils offer little resistance to the flow of corrosion currents. It is also significant that 37 (55 percent) of the culverts that performed satisfactorily (75 and 90 rated) fell within this same range.

Surface-water resistivities from 72 sites were analyzed with respect to culvert condition. These values ranged from a low of 2.48 Ω · m to a maximum of 195 Ω · m, and are also shown in Table 1. It is difficult to discern a direct relationship of surface-water resistivity to culvert condition. Forty-nine (68 percent) of the sites tested contained water of resistivity less than 45 Ω · m, which indicates a susceptibility to interior corrosion. However, a high incidence of interior corrosion was not visually substantiated or evident from other tests. It is important to note that, in two of the three culverts where serious interior corrosion was observed, surface-water resistivities were significantly lower than soil resistivities (water resistivities of 40 and 100 Ω · m, as opposed to soil resistivities of 165 and 280 Ω · m).

The results of resistivity testing indicate a relationship between the general aggressiveness of the site and the soil and surface-water resistivity. However, it is not a cause-and-effect relationship, nor is it reliable enough by itself to predict culvert corrosion rates. Resistivity's major contribution appears to be in identifying potentially corrosive environments where further testing should be conducted.

Spontaneous potentials were monitored at each culvert site for anomalous values. Comparison of these potentials reflected no evidence of stray currents from any source. These results indicate that stray current corrosion was not a significant factor in culvert deterioration.

The soil and surface-water pH measurements were performed throughout the state at test sites that represented a variety of land uses, soil types, and geologic features. As shown in Table 2, average soil pH values and ranges for rating classes are similar but do not reveal any obvious relationships between soil pH and culvert condition. Water pH values measured at 173 culvert sites ranged from 5.1 to 8.6 and averaged 6.8.

Table 2. Comparison of corrosion rating class for soil and surface-water pH values.

Rating Class	Soil pH			Surface-Water pH		
	Average	Low	High	Average	Low	High
0	6.7	5.4	8.4	6.7	5.7	8.4
25	6.8	5.6	9.0	6.8	5.1	8.4
50	6.7	4.9	8.1	6.7	5.3	8.3
75	6.7	5.8	8.0	6.8	5.8	8.6
90	6.9	5.7	8.6	7.0	5.9	8.3

Table 3. Comparison of corrosion rating class and environmental parameters with actual ratings.

Corrosive Classification	Environmental Parameters: Soil Texture	Drainage	Water-Table Depth	Soil Permeability	No. of Occurrences in Actual Ratings: Rating Class 0	25	50	75	90	Combined
Little or none	Granular	Well	Deep	Excellent	0	0	0	0	1	1
Mild	Granular, granular-cohesive	Moderately well to well	Occasionally at culvert flow line	Good to excellent	2	2	4	4	5	17
Heavy	Cohesive, granular-cohesive multiple soil contacts	Poorly to imperfectly	Permanently above culvert flow line	Poor	6	17	17	13	11	64
Severe	Organics, cohesive	Very poor to poorly	Permanently above land surface	Very poor	22	20	26	13	6	87
Total					30	39	47	30	23	169

Surface water on a site-to-site basis tended to be more neutral than the soil, but, in two cases where interior corrosion was observed to be more severe than exterior corrosion, the water was conspicuously more acidic than the soil.

A meaningful empirical association between metal culvert corrosion and various environmental factors such as soil texture, drainage, water-table depth, and soil permeability is difficult to establish. Nevertheless, these factors are used by several agencies as criteria for selecting culvert material and thus required investigation in this study (10). Information reported on 1920 installations inspected during phase 1, along with field experience, provided most of the input for this analysis. Certain relationships were evident, but only in very general terms. Several combinations of factors were evaluated in the process of developing the parameters of Table 3. This table must be viewed as presenting only highly generalized corrosive trends, not absolute direct correlations.

On a statewide basis, 169 culvert installations that had service histories of 10-14 years were classified according to this system. A comparison of actual culvert performance with site classification is shown in Table 3. From this display it can be seen that 28 percent (43 of 151 culverts) performed satisfactorily, even though they were installed in sites classified as heavily or severely corrosive. Furthermore, premature failure was to occur in at least 8 of 17 sites (47 percent) classified as mildly corrosive.

Practical field experience clearly indicates the fallacy of using these types of classification systems for predicting corrosive areas. In addition, this experience confirms that only those sites included in the little-or-none corrosion group were reliably classified.

Average concentrations of chloride and sulfate in the soil were compared to the visually rated culverts and are shown below.

Rating Class	Average Measured Soil Concentrations: Chloride (ppm)	Sulfate (ppm)
0	181	88
25	142	65
50	146	76
75	99	57
90	95	58

Although these ion concentrations vary considerably from site to site, a general correlation can be noted between measured dissolved chemical concentrations and culvert performance.

To further examine this relationship, chemical data were combined with soil pH, moisture content, and minimum resistivity values and then statistically analyzed. The statistically representative model, established to provide an unbiased evaluation, consisted of a random generation of 30 observations from each of the five rating classes (150 observations in all). Model verification was accomplished through a comparison of individual parameter means and standard deviations for the model and for the full population. In addition, model and population parameters were evaluated by test statistics and two-tailed significance tests at the 95 percent confidence interval.

Stepwise multiple linear regression ranked the measured parameters according to their partial correlations with culvert performance. The dependent variable in this analysis was culvert performance as denoted by an assigned rating from 90 through 0. The stepwise analysis ranked the parameters in this order: chloride, minimum resistivity, pH, moisture content, and sulfate. These variables had a multiple correlation coefficient of 0.31 and a standard error of estimate of 31.7. Only 9.6 percent of the dependent variable variation is explained by the regression equation developed from these parameters.

It becomes apparent that there are variables other than those considered in this regression analysis that are responsible for culvert deterioration. Many of these other parameters may be intangible factors that do not lend themselves to statistical evaluation. Therefore, a direct test, break polarization, was considered as a means of appraising soil corrosiveness.

This method measures the instantaneous composite effective value of corrosion currents. It is based on the premise that a metal in contact with an electrolyte (moist soil) produces one or more corrosion cells that can be represented as a single cell. This cell is composed of an anodic and a cathodic element, and any change in either element results in a corresponding change in the cell potential. Corrosion current generated by the cell can be determined by monitoring changes in the electrical potential between the metal specimen and the soil, while a varying external current is applied both cathodically and anodically. Laboratory polarization tests were conducted on 239 soil samples from the study sites, including a number of duplicate samples for evaluating test repeatability.

Test results show a direct relationship between corrosion currents measured on laboratory polarization-test samples and the actual field performance of metal culverts exposed to their in situ soils. The nature of this relationship is shown below.

Rating Class	Mean Corrosion Current (mA)	Standard Deviation (mA)
0	0.785	0.122
25	0.661	0.091
50	0.542	0.075
75	0.497	0.042
90	0.433	0.040

An inverse relationship does exist: As corrosion currents increase, culvert performance worsens.

To obtain a more exact accounting of association between the corrosion current and the visual rating, a linear regression was performed on 218 observations. Visual rating was the dependent variable and corrosion current (i_0) the independent variable. A correlation coefficient of 0.78 (standard error of estimate of 18.8) was obtained, which demonstrates a significant correlation between the polarization-test results and culvert performance.

Polarization data were then combined with all of the measured parameters for a stepwise multiple linear regression that used an unbiased model comprising 30 observations from each of the five visual rating classes. The total culvert population averaged 12 years' service. The average gauge was 14. Regression variables (corrosion current, natural moisture content, soil chlorides, gauge, soil pH, years of service, minimum resistivity, and soil sulfates) revealed a correlation of 0.91 and a standard error of estimate of 13.7. Comparisons of the effects of each variable on the multiple correlation coefficient, coefficient of determination, standard error of estimate, and t-values indicate that only corrosion current and the natural moisture content of the soil are significant at the 95 percent level of confidence. Corrosion current is significant at the 99 percent confidence level. A multiple linear regression using corrosion current (i_0) and percentage of natural moisture content (moist) derived the regression equation

$$\text{Culvert rating} = 187.10 + (-236.39)(i_0\ \text{mA}) + (-4.97)(\%\ \text{moisture content}) \quad (1)$$

These variables accounted for 82.9 percent of the variation in the dependent variable and a correlation of 0.91 with a standard error of estimate of 13.6.

As a check on how well the regression equation represents the entire population, values from those population observations not selected for use in the randomly generated model were substituted in the equation. Data points from three rating classes, which did not represent the entire range of the regression equation, produced a standard error of estimate of 7.1.

This statistical analysis demonstrates that the two variables, polarization corrosion current and percentage of natural moisture content, can predict the condition of a 14-gauge galvanized culvert at the end of a 12-year period within reasonable limits. Further refinement will make this evaluating technique a more useful tool for selecting culvert material. Predicting time until culvert perforation by using test results can provide essential aid to the design and evaluation of future culvert installations.

Some states have developed zoning systems for restricting the use of galvanized CMP culverts (10, 11). These areas are generally founded on iso-pH maps, resistivity maps, great soil groups, and areas of high incidence of corrosion. This type of approach works particularly well where distinct abnormal conditions prevail, which is not the case in Michigan. In fact, average values and ranges of measured parameters (pH, resistivity, and chemical concentration) suggest a uniformity throughout the state. However, geology and soil conditions change so rapidly over short distances that boundaries drawn on any of these parameters would be meaningless. In Michigan's two great soil groups (Gray-Brown Podzolic and Podzolic) perforated-culvert frequency differs little or not at all. Evaluation of the frequency of severely corroded culverts on a district-by-district basis suggests a homogeneity that would discourage use of a zoning system. Michigan's culvert-corrosion problem does not lend itself to such a simple solution.

CONCLUSIONS

The statewide evaluation of galvanized CMP culvert installations that had service histories ranging from 2 to 40 or more years involved the following steps and conclusions.

1. An inspection program of a total of 1920 culverts revealed that 139 culverts or 6.7 percent were seriously corroded.
2. This study and the previous I-75 study indicate that corrosion primarily attacks culvert exteriors and that the soil serves as the major corrosive agent in this attack.
3. Resistivity is not a corrosion-rate predictor; its significance lies in identifying potentially corrosive environments and sites where test samples should be taken.
4. Spurious electrical currents, as monitored in this study, did not contribute to culvert deterioration.
5. Soil and water pH values did not relate directly to culvert condition.
6. A generalized site-evaluation chart was developed by using the empirical parameters of soil texture, drainage conditions, water-table depth, and relative permeability. Limited application of this site-evaluation system encountered large errors in classifications. The only reliable corrosion class appears to be "little or none" at sites that have well-drained, granular-textured soils of excellent permeabilities and deep water tables.
7. The statistical evaluation of the chemical parameters, soil chlorides, and sulfates along with minimum resistivity, natural moisture, and pH indicated a correlation of 0.31. A regression equation that used these parameters had a standard error of estimate of 31.7 and explained only 9.6 percent of the data variation. This suggests that other intangible variables play a major part in culvert deterioration.
8. Corrosion currents (i_0) measured in the laboratory by polarization were statistically evaluated in combination with parameters for natural moisture content, soil chlorides, culvert gauge, soil pH, years of service, minimum resistivity, and soil sulfates as to their relationship to culvert condition. Only corrosion current and natural moisture content were found to be significant predictors. Regression Equation 1 has a correlation of 0.91 and accounted for 82.9 percent of the dependent variation. These variables can predict the condition of a 14-gauge galvanized CMP culvert at the end of 12 years' service within reasonable limits.
9. A geographical zoning of the state to delineate areas where galvanized CMP culverts can or cannot be used is not feasible.

REFERENCES

1. R. W. Noyce, R. W. Ostrowski, and J. M. Ritchie.

Corrosion of Galvanized Metal Culverts. TRB, Transportation Research Record 539, 1975, pp. 38-49.
2. R. W. Noyce and R. W. Ostrowski. An Assessment of Soil Aggressiveness Towards Buried Metal. Michigan Department of State Highways and Transportation, Lansing, 1975.
3. J. E. Haviland, P. J. Bellair, and V. D. Morrell. Durability of Corrugated Metal Culverts. New York State Department of Transportation, Albany, Nov. 1967.
4. B. H. Welch. Pipe Corrosion and Protective Coatings. Materials and Test Division, Utah State Department of Highways, Salt Lake City, Nov. 1974.
5. Field Manual of Soil Engineering. Michigan Department of State Highways, Lansing, 5th Ed., Jan. 1970.
6. J. L. Beaton and R. F. Stratfull. Field Test for Estimating Service Life of Corrugated Metal Pipe Culverts. Proc., HRB, Vol. 41, 1962, pp. 255-272.
7. J. T. Ellis. Corrosion Performance of Aluminum Culverts: Second Progress Report. Michigan Department of State Highways, Lansing, 1968.
8. J. S. Dana and R. J. Peters. Corrosion of Highway Structures. Materials Division, Arizona Department of Transportation, Phoenix, Aug. 1969.
9. R. W. Noyce. Statewide Galvanized CMP. Culvert Corrosion Survey—Final Report. Michigan Department of State Highways and Transportation, Lansing, 1976.
10. Handbook of Steel Drainage and Highway Construction Products. American Iron and Steel Institute, New York, 2nd Ed., 1971.
11. L. W. Hyde, V. M. Shamburger, J. S. Ellard, and R. E. Pate. Detrimental Effects of Natural Soil and Water Elements on Drainage Structures in Alabama. Alabama University, Montgomery, Alabama Highway Research Rept. HPR-40, 1969.

Publication of this paper sponsored by Committee on Corrosion.

Abridgment

Development of a Porous Lane-Marking System

Quentin L. Robnett, Georgia Institute of Technology, Atlanta

The lack of adequate lane guidance at night under wet conditions is a particularly critical highway-safety problem. Water on the pavement surface contributes to increased glare and a general loss in visibility of lane-marking stripes. Recently, significant effort and resources have been devoted to the development of new traffic-control materials, devices, and related delineators to assist the traveling public during adverse weather conditions and night driving (1).

In southern states the problem of wet-night lane marking has been solved largely by supplementing conventional lane stripes with raised reflective markers. In northern states where snowplows are used, however, such markers are impractical, and other solutions are needed.

Open-graded asphalt friction courses (OGAFC) or porous friction courses, although developed primarily for other reasons (2), have helped reduce the wet-night lane-stripe visibility problem. The porous nature of OGAFC minimizes or eliminates the time during which the pavement surface and delineator stripe are inundated. The reflective material is thus more effective and headlight glare is minimized.

There are certain undesirable features in using conventional and hot-applied thermoplastic lane-striping materials and raised pavement markers (RPM) with the porous OGAFC: (a) greater required quantities of striping materials, (b) restriction to lateral flow of water, (c) more rapid loss of RPM, and (d) incompatibility of snowplows with RPM.

PURPOSE OF THE STUDY

It was hypothesized that a better lane-striping system for the increasingly popular OGAFC might be one that uses the same porous, open-graded principle. A research project was therefore initiated to develop and field test a snowplow-resistant lane-delineation system that possessed porosity and texture characteristics similar to that of OGAFC and provided adequate lane-stripe visibility at night under rainy conditions.

MIXTURE DEVELOPMENT AND EVALUATION

The special delineator system, in order to exhibit a porous, open-graded texture and have appropriate color and light-reflecting qualities, should be composed of the following key ingredients.

1. Aggregate: High porosity is obtained by using a narrow-graded aggregate with no appreciable fines content. The aggregate used in the porous delineator system acts primarily as an inert material that establishes the skeleton of the porous system.
2. Binder material: A very critical component of the porous delineator system is the binder. It must have sufficient strength, durability, and toughness and must adhere to aggregate and glass beads and be able to be pigmented white or yellow.
3. Color pigment: The pigment mixed with the