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CONDITION OF LONGITUDINAL STEEL IN ILLINOIS CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS

(IHR - 36)

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Bureau of Materials and Physical Research

CONDITION OF LONGITUDINAL STEEL IN ILLINOIS CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS

by

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Interim Report

IHR-36

Continuously Reinforced Concrete Pavement

A Research Project Conducted by
Illinois Department of Transportation
in cooperation with
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16. Abstract

An investigation was made of several CRC pavements constructed within Illinois to determine the extent of corrosion occurring on the longitudinal reinforcement at transverse cracks. The effect of crack width, crack spacing, depth of reinforcement, slab thickness, and type of reinforcement were studied to determine their influence on the progression of corrosion. An analysis was made of 151 cores removed from 12 experimental pavements previously constructed throughout the State for an intensive study on the behavior of a variety of CRC pavement designs. The investigation also includes observations of 23 cores removed from the old Vandalia test pavement, which is of special interest because of its performance history and age.

Of the cores removed from the experimental pavements, 49 percent showed no evidence of active steel corrosion, 50 percent indicated slight pitting to moderate pitting and less than one percent showed advanced rusting with a marked reduction in cross-sectional area of the reinforcing steel. The findings indicate that corrosion of the steel reinforcement in adequately designed CRC pavements is relatively minor, and that corrosion of the steel does not appear to be a potential problem with pavements designed in accordance with the present criteria.

Of the parameters investigated, crack width appeared to be the only significant factor influencing the progression of corrosion. The entrance or ejection of water through transverse cracks was evident in all cores. Some discoloration was noted at all cracks.

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CRC pavement, concrete pavement durability, corrosion, reinforcement, infiltration water, intrusion foreign material, crack width, reinforcement depth, transverse crack interval, core analysis	

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INTRODUCTION

Corrosion of the longitudinal steel reinforcement at transverse cracks in continuously reinforced concrete (CRC) pavements is recognized as a potential source of early deterioration that conceivably could reduce the service life of pavements. This study was undertaken to determine whether any corrosion that might reduce the serviceability of the longitudinal steel of CRC pavements, or that might indicate an undesirable progression that would later become harmful, is present in existing typical pavements in Illinois. Secondary study objectives also were established to evaluate the relationship that might exist between corrosion and known parameters influencing corrosion and pavement behavior, and to determine the degree of intrusion of foreign matter into transverse cracks.

This report describes the procedures used to investigate the corrosion of steel at transverse cracks in various CRC pavements throughout the State, and presents the findings of this investigation.

In 1961, the Illinois Department of Transportation began an intensive study of CRC pavements in cooperation with the Federal Highway Administration. The study included construction of several experimental sections of CRC pavements throughout the State to determine the significant relationships that exist between pavement behavior and certain design variables. Because a growing concern had developed as to the possible detrimental effects of steel corrosion on the structural behavior of CRC pavements, a decision was made to investigate the condition of the reinforcement within existing CRC pavements to determine the extent of corrosion occurring at transverse cracks.

Experience has shown that closely spaced transverse cracks develop throughout most of the length of continuously reinforced pavements and that these cracks generally remain tight when adequate longitudinal reinforcement is provided. The primary function of the steel reinforcement is to hold transverse cracks tightly closed to provide adequate aggregate interlock for maintaining the structural integrity of the pavement, and to reduce infiltration of corrosive salt water and intrusion of incompressible foreign matter. The Illinois Department of Transportation adopted a bare pavement policy during inclement weather conditions that has resulted in a large increase in the use of deicing chemicals over the past 15 years. The rate of increase is shown in Figure 1. It has been of much concern that this increase in the use of deicing chemicals could cause excessive steel corrosion at transverse cracks which would greatly reduce the service life of the pavement.

The use of continuous reinforcement in portland cement concrete pavements to eliminate transverse construction joints and open cracks was conceived about 50 years ago. By the time this investigation was implemented, experimental use of CRC pavements had demonstrated the practicality of this type of construction, and CRC pavement had been adopted as standard practice for the construction of rigid pavements for the interstate and other major highways in Illinois.

The oldest continuously reinforced pavement in Illinois was constructed as an experimental project in 1947-48 on Route US 40 west of Vandalia 1/. The need to remove a portion of the experimental pavement in 1965 provided an opportunity to observe closely the condition of the steel after 18 years of service. Very slight rusting was commonly found on the surface of the reinforcement at transverse cracks, but the degree of rusting was considered to be minor. Cores taken

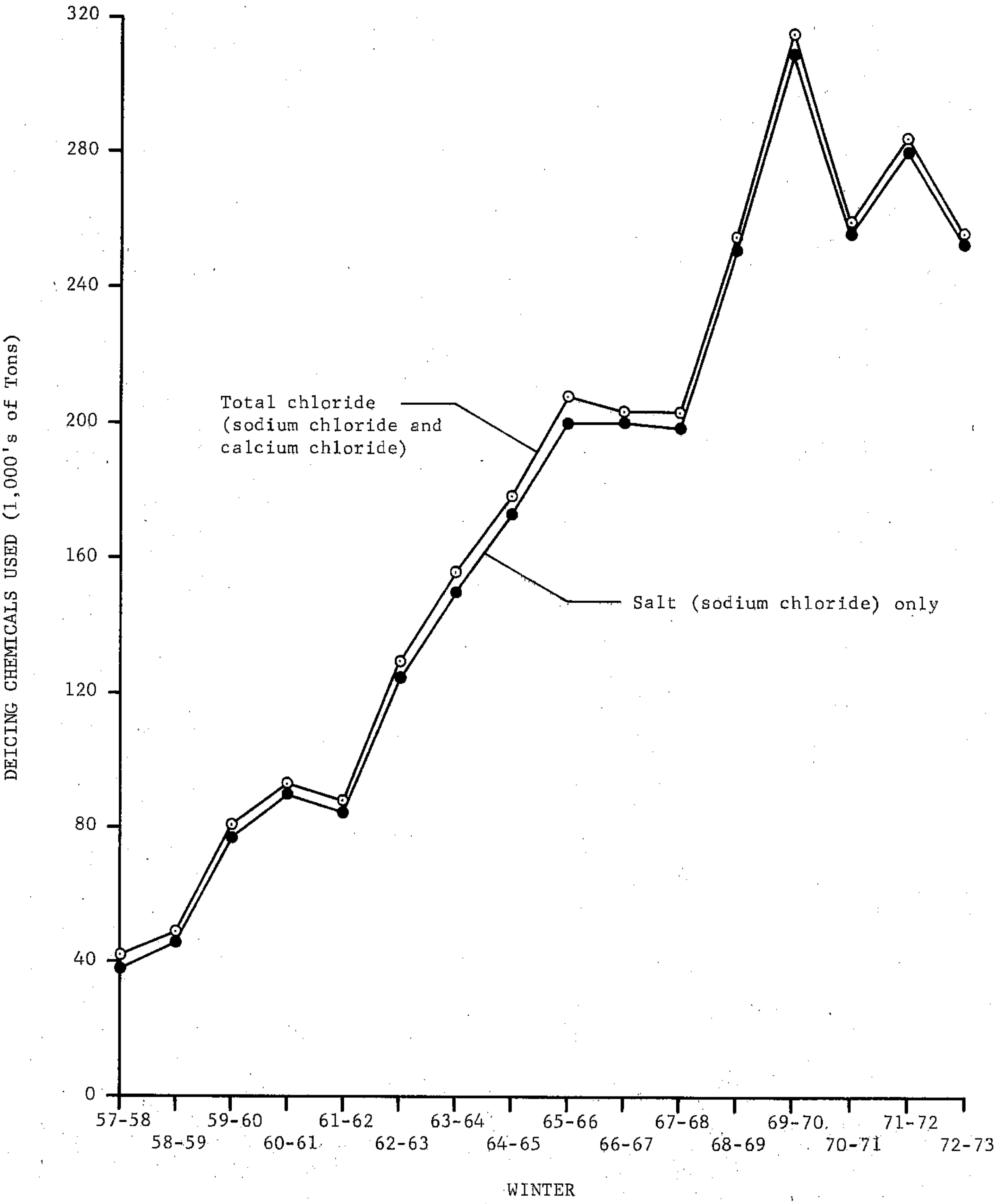

Figure 1. Use of deicing chemicals on Illinois highways for snow and ice removal.

from other locations within the pavement in 1967 also showed only a negligible amount of rusting of the longitudinal reinforcement 2/.

This report comprises an evaluation of 151 cores removed from 12 experimental pavements constructed throughout the State during 1963-66, and of 23 cores removed from the old Vandalia test pavement constructed in 1947-48. The findings indicate that corrosion of the steel reinforcement in adequately designed CRC pavements is relatively minor, and that corrosion of the steel does not appear to be a potential problem with pavements designed in accordance with the present criteria. Discoloration indicating infiltration of water and brine was evident in all cores. Water and brine had penetrated even through fine openings normally considered hairline or tight cracks. The findings, however, indicate no signs of structural distress attributable to the intrusion of foreign material into the cracks.

STUDY DETAILS

A coring program was undertaken in early 1970 to obtain specimens to reveal the extent of corrosion occurring within existing CRC pavements and to identify the relationship of certain design and environmental factors associated with pavement behavior that might influence the progression of corrosion. The pavements investigated consisted of (1) the experimental pavements currently under observation, and (2) the old Vandalia test pavement. The general location of each pavement included in this investigation is shown in Figure 2.

Estimates of the total tonnages of salt applied per two-lane mile for these pavements are included in Table 1. With the exception of test sites 2 and 3, the average tonnage per two-lane mile per year for rural pavements varied from 4 to 18 tons. Test sites 2 and 3 are on Chicago Metropolitan expressways, and each received an average of 72 tons per two-lane mile per year.

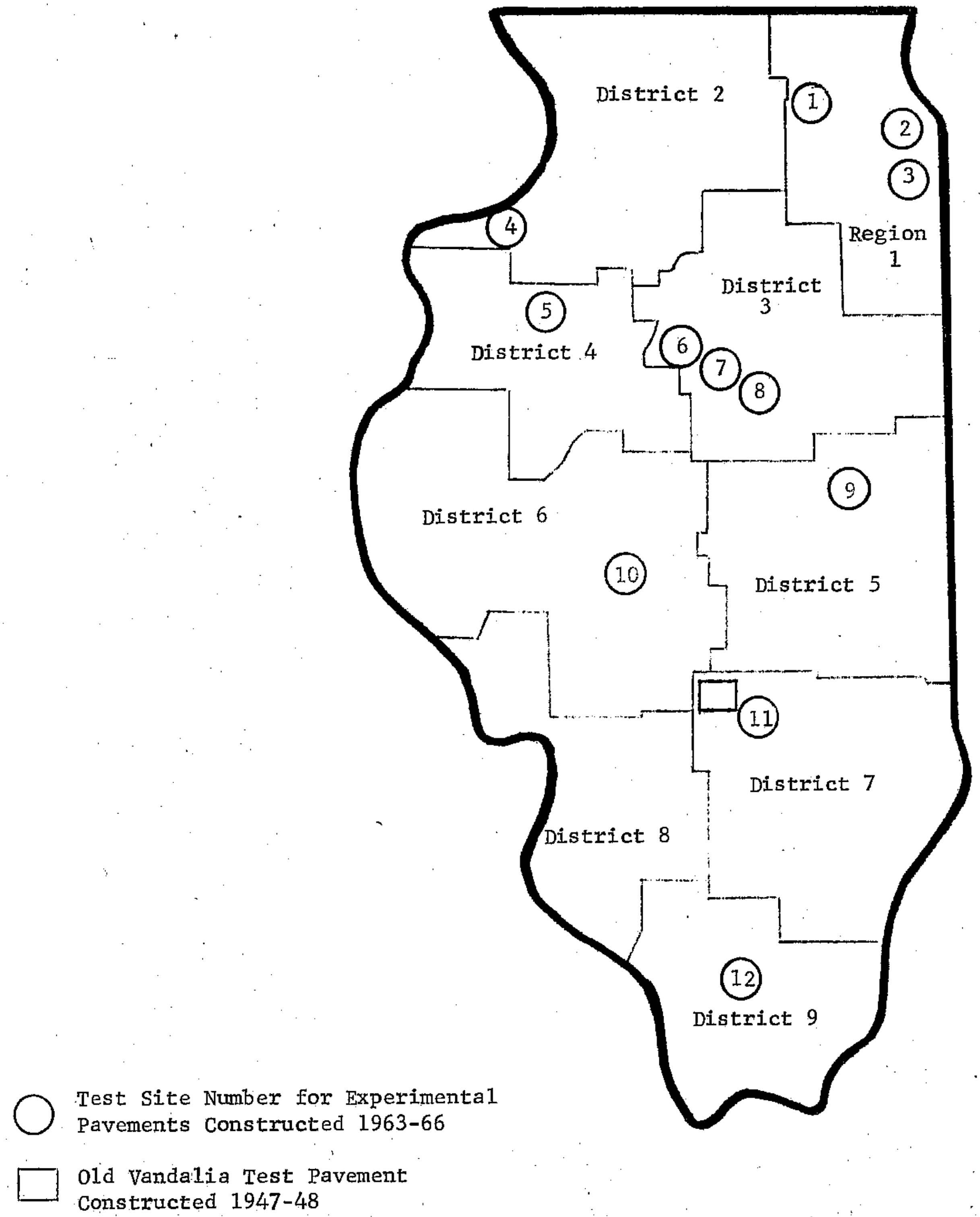

Figure 2. Location of pavements investigated.

TABLE 1

ESTIMATED TONS OF SALT APPLIED TO PAVEMENTS

Test Site Number	Region or District	Tons per 2-Lane Mile per Year	Years Applied	Total Tons
1	1	18	6	108
2	1	72	7	504
3	1	72	6	432
4	2	4	6	25
5	4	10	6	60
6	4	10	5	50
7	4	10	4	40
8	4	10	4	40
9	5	8	5	40
10	6	4	4	16
11	7	7	7	49
12	9	6	5	30
13 (Old Vandalia)	7	7	21	147

A total of 151 cores were removed from the experimental pavements now under observation as part of research study IHR-36. These pavements, consisting of 12 projects located throughout the State, were constructed during 1963-66 to obtain comprehensive information relative to the behavior and serviceability of CRC pavements. The study includes an evaluation of various design parameters that were incorporated into the experimental pavements to determine their significance in relation to pavement behavior and serviceability.

These experimental pavements offered an opportunity to study the influence on steel at cracks of several relevant variables at a number of levels. Furthermore, they have provided valuable research data histories that have been accumulated since their construction. A listing of the test sites by location, with corresponding experimental features and number of cores removed from each test section, is given in Table 2.

The variables included to investigate the condition of longitudinal steel are as follows:

(1) Transverse crack width - at steel level

(2) Depth of reinforcement - 2 in., 3 in., and mid-depth

(3) Transverse crack spacing - 0-1 ft, 4-5 ft, 8-9 ft, 12-13 ft, and 15 ft+

(4) Steel type - deformed bars and welded deformed wire fabric

(5) Age - 4 to 7 years

(6) Traffic load applications - moderate to heavy

The effect of the pavement thickness, and the type and thickness of the subbase, were omitted from the analysis.

The project in District 6 (Test Site 10) was instrumented with strain gages and other devices for an intensive study of a CRC pavement within one geographic location. This pavement contains most of the design parameters included in the study, and limits these parameters to a common location that minimizes variations due to environment,

TABLE 2.

CORES REMOVED FROM EXPERIMENTAL PAVEMENTS
(total 151 cores)

Test site Number	Route	Section Number	County	Year Built	Slab Thickness (in.)	Reinforcement Type	Reinforcement Depth (in.)	Crack Spacing (ft.) 0-1	4-5	8-9	12-13	15+
								(number of cores)				
1	FA 7	6R-1,5R	Kane	1964	6	bars	2	2	2	-	-	-
				1964	7	bars	2	2	2	-	-	-
2	FA 61	531-1	Cook	1963	8	bars	3	2	2	1	-	-
3	FAI 55	1314-638	Cook	1964	10	fabric	3.5	2	2	-	-	-
4	SBI 3	7R,7RB	Rock Island	1964	8	fabric	2	2	2	1	-	-
				1964	8	fabric	3	2	2	2	-	-
				1964	8	fabric	4	1	2	2	-	-
5	FAI 74	48-27	Knox	1964	7	bars	2	2	2	-	-	-
				1963	7	bars	3.5	-	2	2	-	-
				1963	7	fabric	3.5	2	2	2	-	-
6	FAI 74	90-16	Woodford	1965	7	bars	3	2	2	-	-	-
7	FAI 74	57-17	Woodford	1966	7	fabric	3	2	2	2	-	-
8	FAI 74	57-18	McLean	1966	7	bars	3	2	2	-	-	-
9	FAI 57	10-32	Champaign	1963	7	bars	3.5	1	-	2	2	2
				1963	8	bars	4	-	-	2	2	2
10	FA 196	2-1	Sangamon	1966	7	bars	2	2	2	1	-	-
				1966	7	bars	3.5	-	2	2	2	-
				1966	7	fabric	2	2	2	2	-	-
				1966	7	fabric	3.5	2	2	2	-	-
				1966	8	bars	2	2	2	-	-	-
				1966	8	bars	4	1	2	2	2	-
				1966	8	fabric	2	2	2	1	-	-
				1966	8	fabric	4	-	2	2	2	-

(continued)

TABLE 2.

CORES REMOVED FROM EXPERIMENTAL PAVEMENTS (continued)
(total 151 cores)

Test site Number	Route	Section Number	County	Year Built	Slab Thickness (in.)	Reinforcement Type	Reinforcement Depth (in.)	Crack Spacing (ft.) 0-1 (number of cores)	4-5	8-9	12-13	15+
11	FAI 70	26-3,26-4	Fayette	1963	8	bars	2	2	2	-	-	-
				1963	8	bars	3	2	2	2	-	-
				1963	8	bars	4	2	2	2	2	-
12	FA 14	6-1	Williamson	1964	7	fabric	2	2	-	1	1	2
				1965	7	fabric	3.5	2	2	2	2	-

traffic, and construction practice. Experience with various experimental pavements constructed throughout the State has indicated differences in behavior among the projects. Furthermore, variations in pavement behavior also have been found within single projects. For example, localized problems in drainage have greatly influenced the behavior of the pavement in District 6. Although the performance of this pavement is not considered typical, a large part of the coring effort was concentrated at this location.

In addition to the experimental pavements, 23 cores were removed from the old Vandalia test pavement. This pavement is of special interest from the standpoint of its performance history and age. The location and number of cores removed from the pavements are given in Table 3.

Examination of cores taken from the pavement during previous studies had revealed only slight to very moderate signs of corrosion. The Vandalia pavement, constructed in 1947-48, has provided much of the earlier impetus for the design and construction of CRC pavements in Illinois and elsewhere. The traffic and environmental elements to which the pavement has been exposed are considered typical of conditions now existing for many major highways, with the exception that this pavement is 22 feet wide and placed directly on natural fine-grained soil.

Sampling Procedure

Core samples from the experimental pavements were selected on the basis of crack frequency histograms obtained from crack surveys made during 1968-69. The crack surveys are made at selected locations consisting of 500-ft test segments within each of the experimental pavements, and are repeated at 2-year intervals. These segments were established previously to study the formation and growth of transverse cracks relative to various design features incorporated in the experimental pavements. Histograms showing the typical distribution of the spacing of transverse cracks surveyed during 1968-69 are illustrated in Figure 3. The

TABLE 3.

CORES REMOVED FROM OLD VANDALIA PAVEMENTS
(total 23 cores)

Test site Number	Route	Section Number	County	Year Built	Slab Thickness (in.)	Reinforcement Type	Reinforcement Depth (in.)	Crack Spacing (ft.) 0-1	4-5	8-9	12-13	15+
								(number of cores)				
7	FA 12	0-2	Fayette	1947	7	bars 0.5%	3	2	2	1	-	-
				1947	7	bars 0.7%	3	2	2	2	-	-
				1948	8	bars 0.5%	3	-	2	2	2	-
				1948	8	bars 0.7%	3	2	2	2	-	-

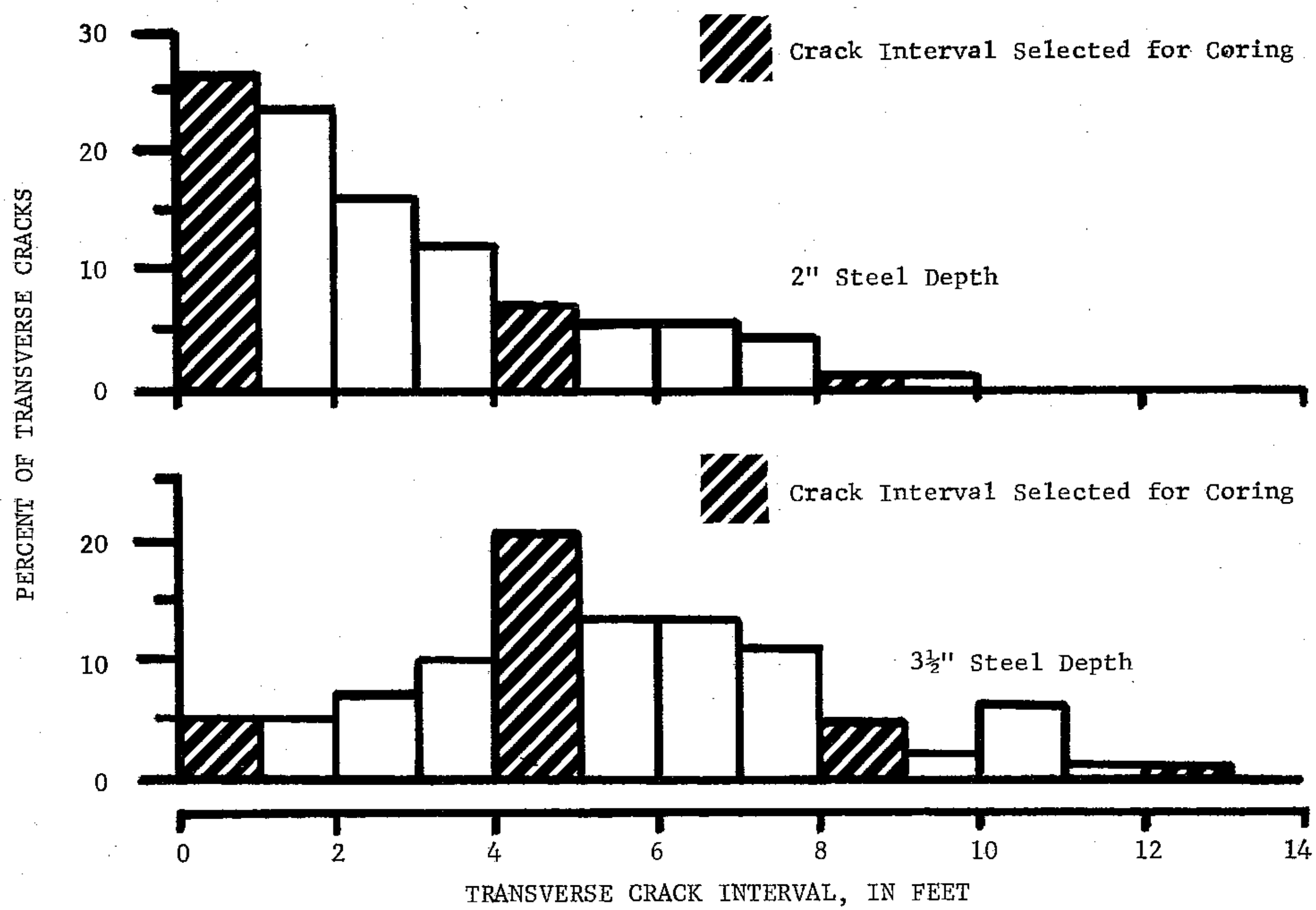

Figure 3. Frequency histograms showing crack interval distributions.

following intervals of crack spacing selected for coring were 1 ft or less, 4 to 5 ft, 8 to 9 ft, 12 to 13 ft, and 15 ft or greater. Duplicate cores were obtained in test segments containing replicate crack spacings within the intervals selected. In some areas, however, the sampling was limited because of the absence of crack spacings representative of the selected space interval.

All cores were taken within the portion of transverse cracks lying in the outer wheelpath of the traffic lane directly over the longitudinal reinforcement. The location of the steel reinforcement was determined with the aid of a Pachometer. The pavement was marked for coring and photographs were taken of the cracked surface width of the crack. Each core was identified, labeled, and transported to the Physcial Research Laboratory where slab thickness, crack width, and steel depth measurements were made. Each core was then opened to expose the condition of the steel reinforcement and the crack interfaces. The results of these observations and measurements are summarized in Appendix A.

Corrosion Ratings

During the planning of the coring program, a rating system was developed to evaluate the condition of the reinforcing steel. The criteria used for classifying the steel reinforcement are as follows:

Rating	
1	Clear or free of rust.
2	Slight rust with no appreciable reduction in cross-sectional area.
3	Moderate rust with no substantial reduction in cross-sectional area.
4	Heavy rust with a marked reduction in cross-sectional area.

A typical sample representing each rating is shown in Figure 4. Among the four classifications, a rating of "4" is the only corrosive condition indicative

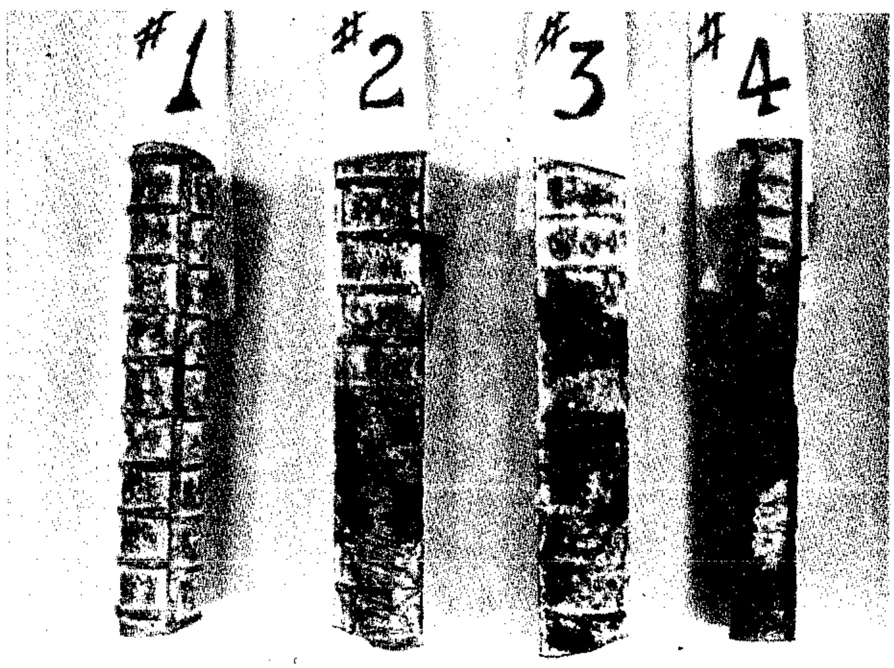

Figure 4. Photograph showing typical samples representing each core rating.

of a marked reduction in the strength of the steel, and the only one expected to adversely affect pavement performance. For this rating, the rust layer is generally loose and porous with a marked reduction in cross-sectional area that is visually apparent. Steel rated as "1" shows no evidence of corrosion, whereas steel rated as "2" or "3" indicates a thin layer of localized rust that is generally tight and dry with possible light pitting, but with no evidence of a marked reduction in cross-sectional area. Corrosion associated with classifications from "1" to "3" is considered minor with no significant effect on the service life of the pavement.

EXTENT OF CORROSION ON STEEL REINFORCEMENT

The distribution of cores representing various degrees of corrosion of the reinforcement contained within the experimental CRC pavements constructed during 1963-66 is shown in Figure 5. At the time of coring, the age of the experimental CRC pavements varied from 4 to 7 years, which represents from 20 to 35 percent of the normal 20-year design period before resurfacing is expected.

Of the 151 cores removed from the experimental pavements, 74 cores or 49 percent showed no evidence of corrosion (Rating 1), 61 cores or 40 percent indicated only slight rusting (Rating 2), and 15 cores or 10 percent indicated moderate rusting (Rating 3). Only one core or less than one percent was found with reinforcement having evidence of advanced rusting with a marked reduction in cross-sectional area (Rating 4).

The oldest CRC pavement within the State is the Vandalia test pavement constructed in 1947-48 on Route US 40 west of Vandalia. This pavement served the two-way Route US 40 traffic until 1967 when the heavy traffic was diverted to a

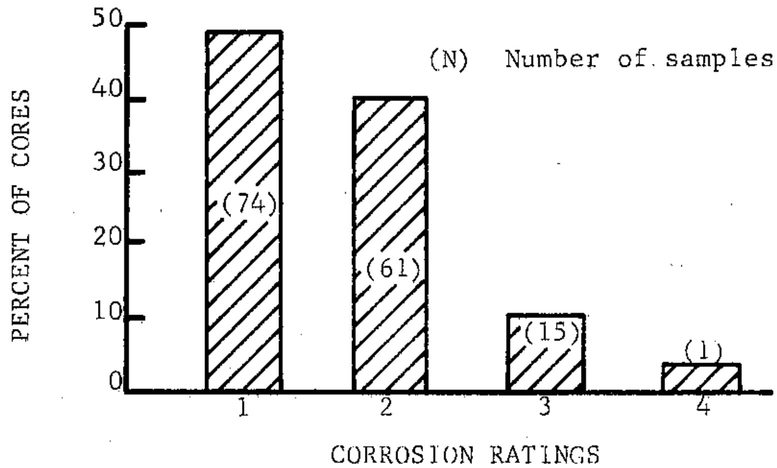

Figure 5. Distribution of core samples versus corrosion rating for experimental pavements.

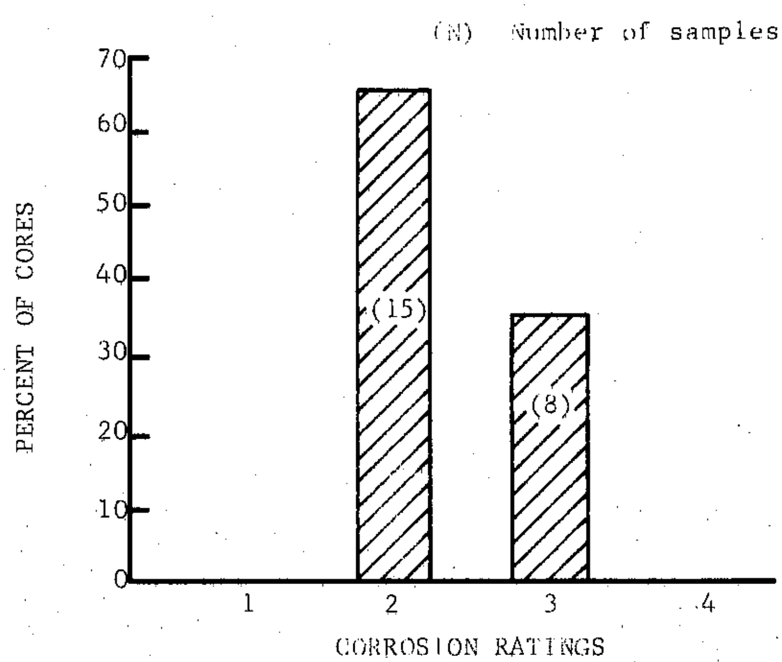

Figure 6. Distribution of core samples versus corrosion ratings for old Vandalia pavement.

newly completed section of Interstate Route 70. Since 1967, the pavement has been serving only local traffic but is still in excellent condition and structurally capable of serving heavy traffic.

The distribution of cores relative to the degree of corrosion found on the reinforcement within the original pavement is shown in Figure 6. Out of 23 cores removed from the pavement, 15 cores or 65 percent indicated slight rusting (Rating 2) and the remaining 8 cores or 35 percent indicated moderate rusting (Rating 3). Advanced corrosion leading to a marked reduction in the cross-sectional area of the reinforcement was not found for any of the cores removed from the Vandalia pavement.

ANALYSIS OF EXPERIMENTAL VARIABLES AND STEEL CORROSION

The following discussion presents an analysis of the data in relation to certain design variables and service conditions that conceivably could influence the development of corrosion of reinforcement within CRC pavements. The parameters included in the analysis are (1) crack width, (2) depth of reinforcement, (3) crack spacing, (4) type of steel reinforcement, (5) pavement age, and (6) traffic load applications.

Crack Width

Aside from the environmental elements, one of the main factors believed having a direct influence on the growth of corrosion is crack width. The width of cracks in CRC pavements has been found to vary for the entire depth of the pavement. Generally, the opening is wider at the surface of the pavement and becomes narrower as it approaches the reinforcement.

Crack-width measurements most nearly representative of the crack opening are difficult to obtain when readings are taken directly at the pavement surface. The apparent width is often exaggerated because of abrasion that occurs under traffic at the edges. The coring program provided an opportunity to determine the crack-width gradient of the opening for the full depth of pavement. However, these measurements may not represent actual crack widths as they exist in the pavement because of the possible disturbance of the samples when they were removed from the pavement.

A summary of the corrosion ratings of the steel reinforcement relative to crack widths measured at the reinforcement is shown in Figure 7. Crack-width measurements were unobtainable from 43 cores which were broken or disturbed when removed from the pavements. Of the remaining 108 cores, 79 cores or 73 percent had crack widths measured at the steel level less than 1/128 inch (measured with a steel scale with 1/64-inch graduations) and 29 cores or 27 percent had crack widths equal to or greater than 1/128 inch.

From the group of cores having crack widths less than 1/128 inch, 47 cores or 60 percent contained reinforcement that was clear or free of rust (Rating 1). The same group also had 28 specimens or 35 percent indicating slight rusting or pitting (Rating 2) and only 4 specimens or 5 percent showing moderate pitting (Rating 3).

Of the 29 cores having crack widths equal to or greater than 1/128 inch, 8 specimens or 28 percent had no evidence of rusting (Rating 1), 14 specimens or 48 percent had slight rusting (Rating 2), 6 specimens or 21 percent had moderate rusting (Rating 3), and 1 specimen or 3 percent had shown advanced rusting with a marked reduction in the cross-sectional area (Rating 4).

The findings indicate that crack widths at the level of the reinforcement equal to or greater than 1/128 inch have a greater potential for steel rusting to develop than do widths less than 1/128 inch.

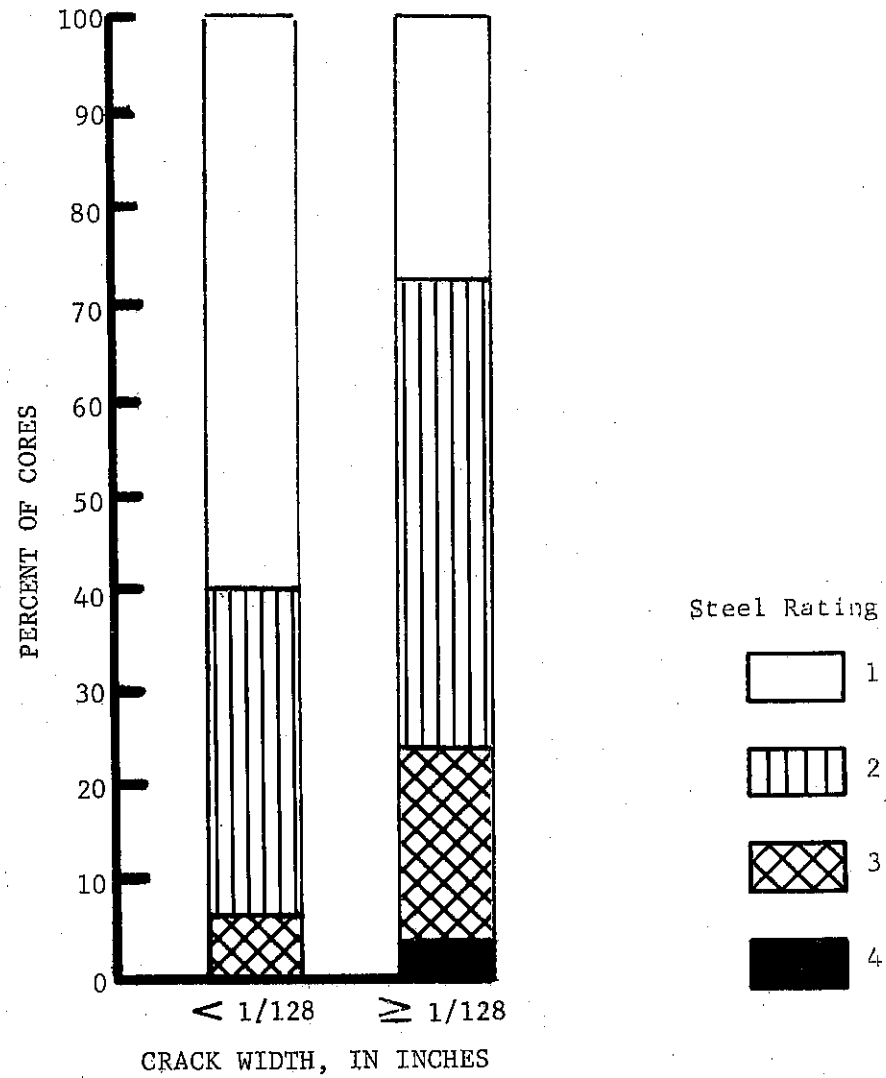

Figure 7. Condition of steel reinforcement versus crack width at steel level.

Depth of Reinforcement

A graph showing the condition of the steel reinforcement relative to the depth of the reinforcement below the pavement surface is presented in Figure 8. The reinforcement depth is measured from the pavement surface to the centerline of the steel. The data used for the analysis are measured values taken directly from the cores and represent the actual depth of the reinforcement as it existed below the pavement surface. The core measurements were grouped in 1/2-inch increments of depth, beginning with a minimum depth of 2 inches. The graph in Figure 8 indicates that the potential for corrosion for depths greater than 2 inches remains about the same regardless of the depth of the reinforcement.

Of the 151 cores removed from the experimental pavements, 22 cores were broken to the extent that depth measurements could not be determined. Of the remaining 129 cores, 22 cores were obtained having depths ranging from 2.0 to 2.5 inches. Within this interval, 11 cores or 50 percent contained reinforcement that was clear or free of rust (Rating 1), 8 cores or 36 percent had slight rusting or pitting (Rating 2), and 3 cores or 14 percent had moderate pitting (Rating 3).

Although the differences between the 1/2-inch intervals is not appreciable, the largest percentage of cores containing steel specimens showing evidence of corrosion was found for the majority of 8-inch pavements having depths exceeding 4 inches. Of 24 cores having the depth of reinforcement greater than 4 inches, 10 cores or 42 percent had reinforcement clear or free of rust (Rating 1), another 10 cores or 42 percent had signs of slight rusting and pitting (Rating 2), and 4 cores or 16 percent had moderate pitting (Rating 3).

The interval with the least percentage of specimens having evidence of corrosion is the group representing the 2.6- to 3.0-inch interval of reinforcement

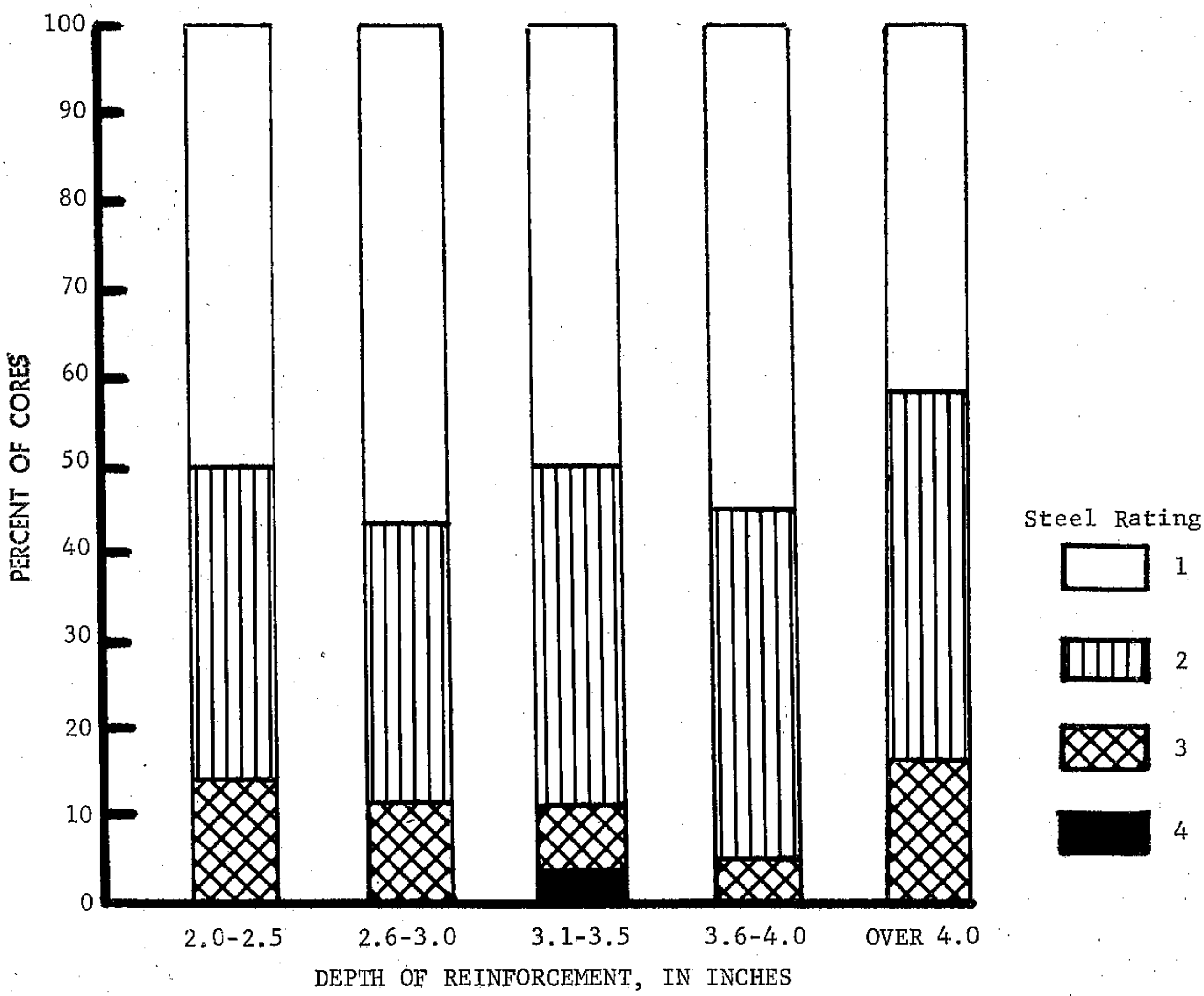

Figure 8. Condition of steel reinforcement versus depth of reinforcement.

depths. Within this interval, 15 cores or 56 percent contained reinforcement clear or free of rust (Rating 1), 9 or 33 percent had indications of slight rusting (Rating 2), and 3 cores or 11 percent had moderate rusting (Rating 3).

The single core containing reinforcement with advanced rusting (Rating 4) fell within the 3.1- to 3.5-inch interval of reinforcement depth.

Crack Spacing

The relationship between the condition of the steel reinforcement and transverse crack spacing is shown in the graph in Figure 9. Of the intervals of crack spacing investigated, the 4- to 5-ft interval had the least percentage of specimens having evidence of corrosion. The condition ratings of the reinforcement found for 50 cores representing the 4- to 5-ft crack spacing interval is comprised of 31 specimens or 62 percent clear or free of rust (Rating 1), 16 specimens or 32 percent slightly rusted (Rating 2), and 3 specimens or 6 percent moderately rusted (Rating 3).

The percent distribution of cores representing the ratings 1 and 2 for crack spacing intervals of 0 to 1 ft, 8 to 9 ft, and over 12 ft are nearly equal, with approximately 42 to 43 percent of the cores having reinforcement clear or free of rust (Rating 1).

Type of Reinforcement

Figure 10 includes a graph showing the condition of the reinforcement relative to the type of reinforcement used in the construction of the CRC pavement. Of 82 cores removed from the pavements reinforced with deformed bars, 43 specimens or 52 percent were clear or free of rust (Rating 1), 28 specimens or 34 percent had slight rusting (Rating 2), and 11 specimens or 14 percent had moderate rusting (Rating 3). Of the 69 cores containing welded deformed wire fabric, 31 specimens

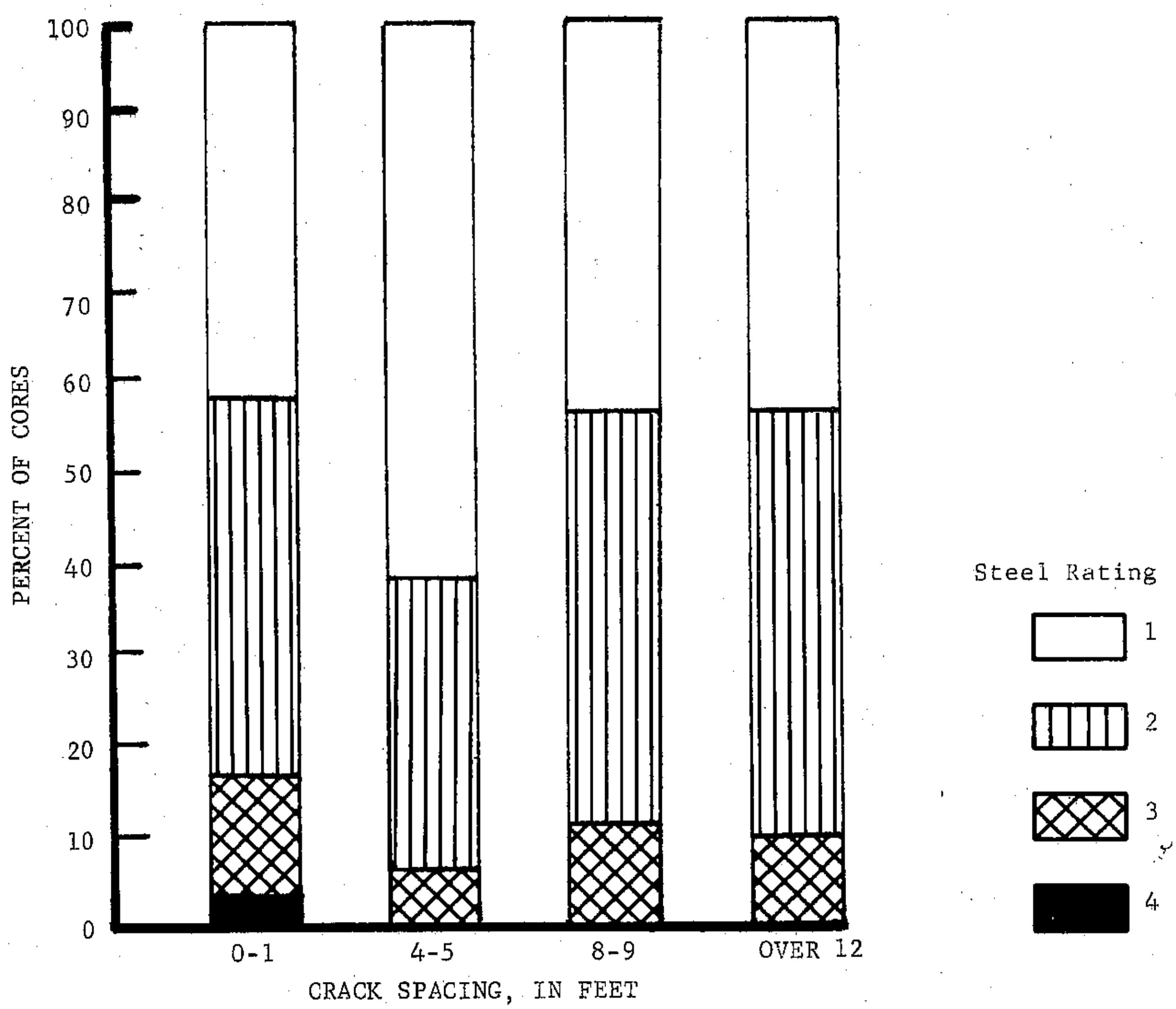

Figure 9. Condition of steel reinforcement versus crack spacing.

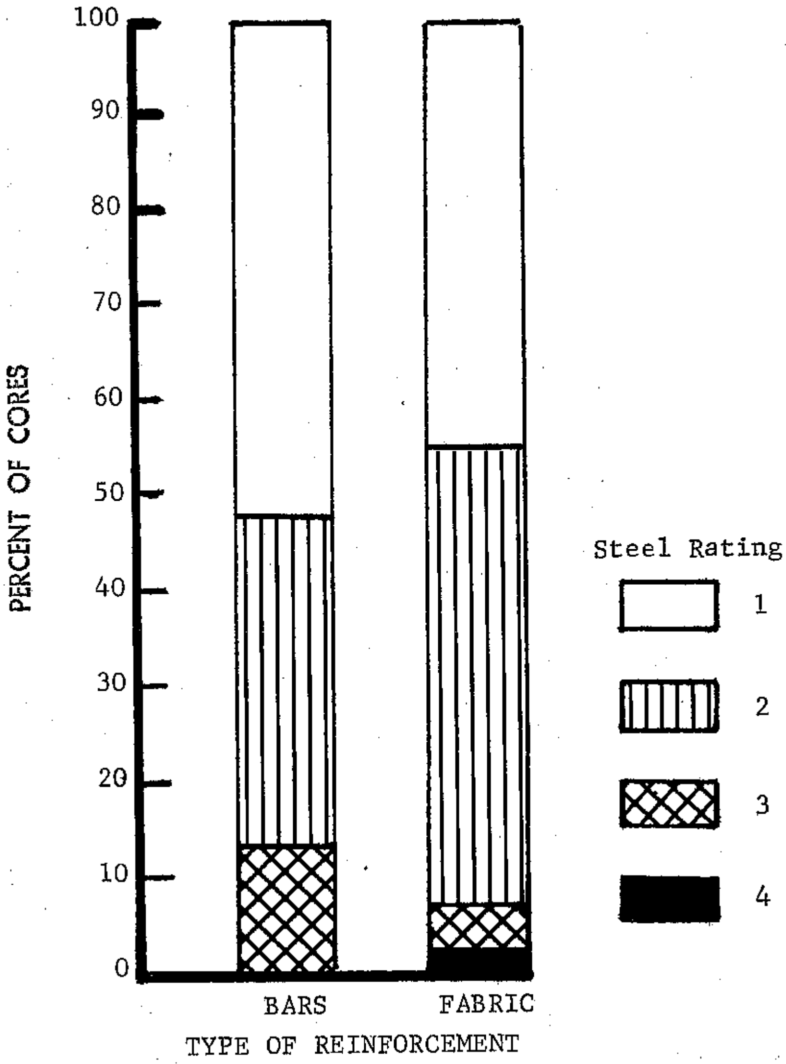

Figure 10. Condition of steel reinforcement versus type of steel reinforcement.

or 45 percent were clear or free of rust (Rating 1), 33 specimens or 48 percent had slight rusting (Rating 2), 4 specimens or 6 percent had moderate pitting (Rating 3), and 1 specimen or 1 percent had advanced rusting, with a marked reduction in the cross-sectional area (Rating 4).

Pavement Age

A chart showing the analysis of the corrosion data with respect to age is given in Figure 11.

The corrosion ratings for each yearly increment from 4 to 7 years of age prior to coring are presented for the experimental pavements constructed in 1963-66. The chart indicates that the youngest pavement constructed in 1966, which was about 4 years old at the time of coring, had the highest percentage of cores showing evidence of corrosion.

Of 55 cores removed from the 4-year-old pavements, 22 cores or 40 percent had steel specimens clear or free of rust (Rating 1), another 22 cores or 40 percent had evidence of slight rusting (Rating 2), 10 cores or 18 percent indicated moderate rusting (Rating 3), and 1 core or 2 percent indicated advanced rusting, with a marked reduction in the cross-sectional area of the reinforcement (Rating 4).

The second highest percentage of cores with corroded reinforcement was found in the oldest pavement constructed in 1963. Of 45 cores removed from the 7-year-old pavement, 19 cores or 42 percent were clear or free of rust (Rating 1), 23 cores or 51 percent showed evidence of slight rusting (Rating 2), and 3 cores or 7 percent indicated moderate rusting (Rating 3).

The increment of pavement age having the largest number of cores clear or free of rust consisted of the 6-year-old pavements constructed in 1964. Out of 31 cores, 22 cores or 71 percent had steel specimens clear of free of rust

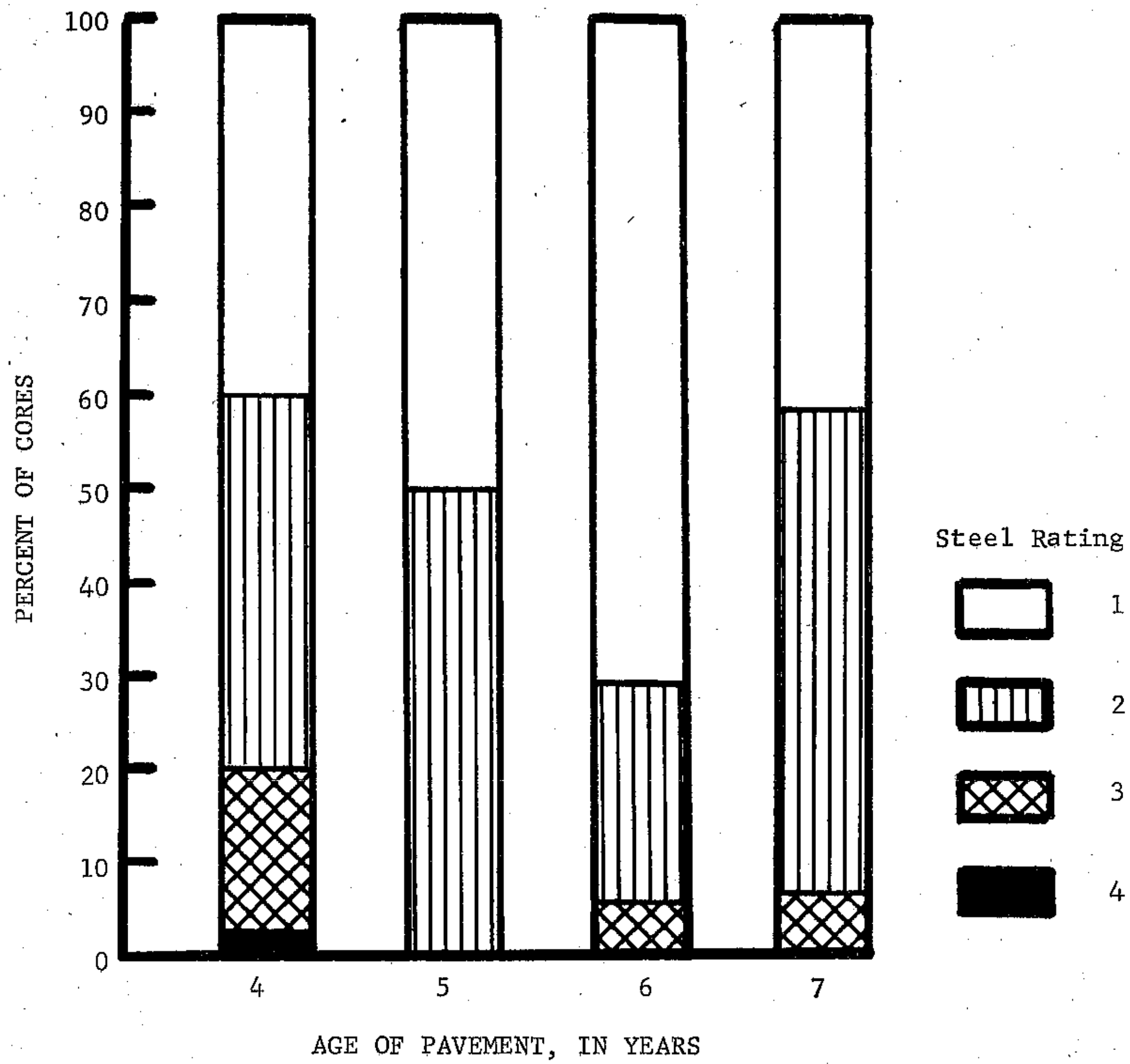

Figure 11. Condition of reinforcement versus age of pavement.

(Rating 1), 7 cores or 23 percent had slight rusting (Rating 2), and 2 cores or 6 percent had moderate rusting (Rating 3).

Traffic Load Applications

A comparison of the steel corrosion ratings relative to variable traffic load conditions is shown in Figure 12. On the basis of equivalent 18,000-lb single-axle loads, the traffic carried by each project pavement since their construction was classified from moderate (0.1 to 0.2 million equivalent 18,000-lb axle applications) to heavy (1.0 to 5.0 million), which represents pavements in both rural and metropolitan areas.

Although the group of cores having the least number of steel specimens with no evidence of corrosion (Rating 1) represented the interval having the largest number of equivalent 18,000-lb single-axle applications, nearly the same percentage of specimens clear or free of rust (Rating 1) was found for the loading interval having the least number of applications.

Of 22 cores representing the 1.0 to 5.0 million axle applications, 8 cores or 36 percent contained steel specimens clear or free of rust (Rating 1), 9 cores or 41 percent had specimens with evidence of slight rusting (Rating 2), and 5 cores or 23 percent with moderate rusting (Rating 3).

From a group of 53 cores removed from the pavements exposed to 0.1 to 0.2 million load applications, 20 cores or about 38 percent had steel specimens clear or free of rust (Rating 1), 22 cores or 41 percent had evidence of slight rusting (Rating 2), and 10 cores or 19 percent indicated moderate rusting (Rating 3). The same group also contained the single core with a specimen showing advanced rusting with a marked reduction in cross-sectional area (Rating 4).

The class of equivalent axle load applications having the least amount of corrosion present was the interval representing 0.3 to 0.5 million axle load

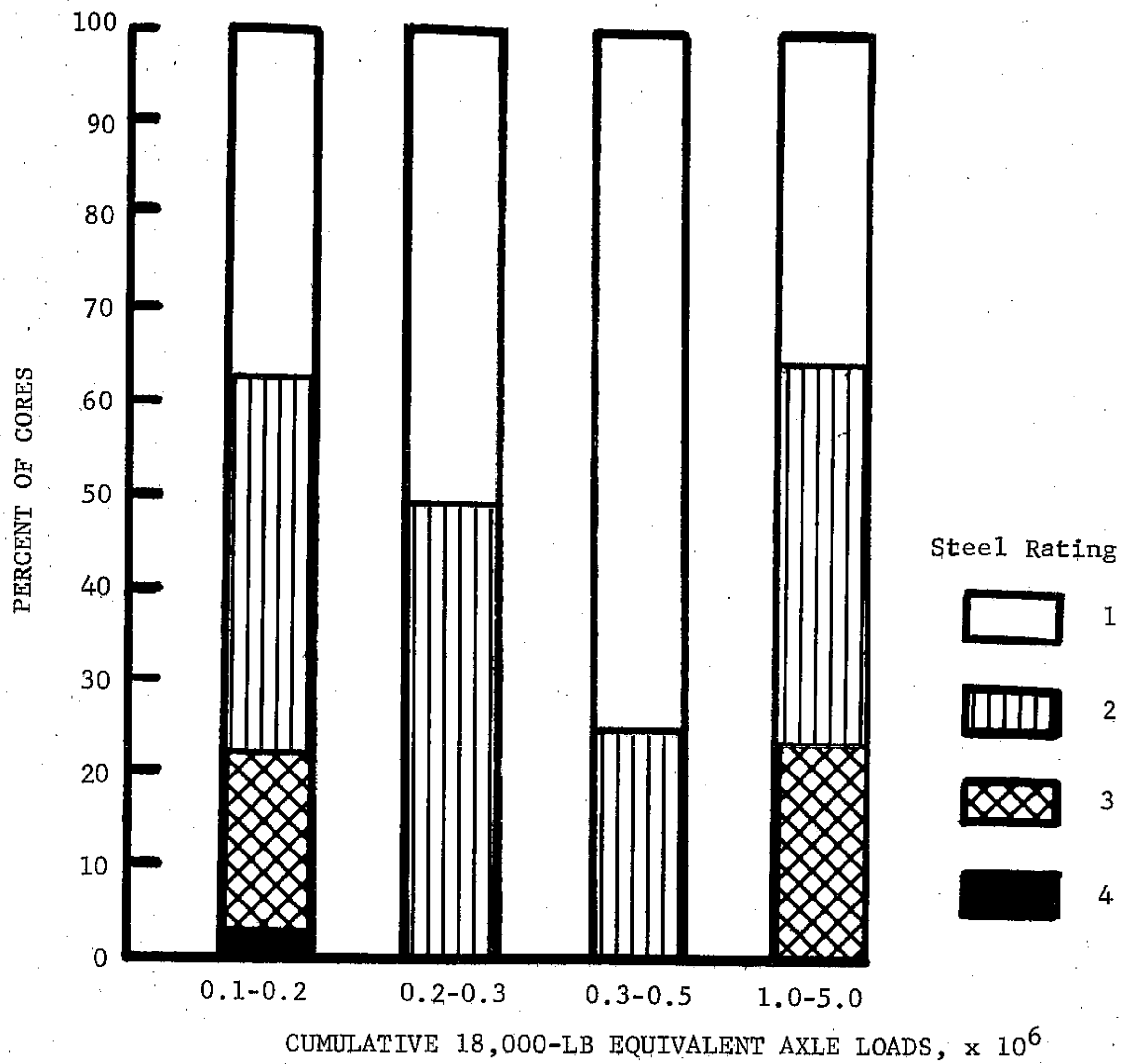

Figure 12. Condition of reinforcement versus traffic.

applications. From a group of 28 cores, 21 cores or 75 percent had no evidence of corrosion (Rating 1), and 7 cores or 25 percent indicated only slight rusting (Rating 2).

INFILTRATION OF WATER AND FOREIGN MATTER

The crack interface of each core was examined to determine the extent of material accumulation due to progressive water infiltration and intrusion of foreign matter. Discoloration of the crack interfaces, indicative of water penetrating through transverse cracks, was evident in all cores with the majority of core interfaces revealing a grey or deep red stain. The condition of the crack faces was classified into two categories: (1) evidence showing only discoloration of the crack interface due to water and soil stain, and (2) evidence showing discoloration and presence of intrusive fine-grained soil accumulation in the crack due to progressive infiltration.

Out of 151 core interfaces inspected, 94 cores or 62 percent were discolored with a layer of soil stain, of which 58 cores indicated that the stain had infiltrated to the steel depth and 36 cores indicated that the stain had completely penetrated the full depth of the core. In addition to the discoloration, the remaining 57 cores or 38 percent contained an accumulation of fine-grained soil.

Although the data revealed that water stains or soil accumulations had penetrated all cracks to some degree, no significant sign of structural damage attributable to the accumulation of the fine-grained soil material was indicated. A significant relationship could not be found between the condition of the crack face and other parameters associated with this study.

DISCUSSION AND SUMMARY

Of the 151 cores removed at transverse cracks from the 12 experimental CRC pavements constructed in 1963-66, the steel in 49 percent of the cores was clear and free of any rust, and only one core, representing less than one percent of the total, had severe rusting, with a marked reduction in cross-sectional area of the steel. These results indicate that steel corrosion is not a serious problem in CRC pavements in Illinois. On the basis of these observations, the extent of corrosion existing in the experimental pavements is very minor, with no apparent effect on the structural integrity of the pavements.

Of the 23 cores removed from the old Vandalia test pavement, the steel in 65 percent indicated slight rusting and in 35 percent indicated moderate rusting. No locations were tested where the steel was completely clear or free of any rusting. Likewise, no locations were found where severe corrosion of the steel had taken place.

The Vandalia pavement was considered of particular interest in this study in that it has already exceeded the normal 20-year design life and has carried for more than 19 years the Route US 40 traffic which is typical of relatively heavy traffic on rural major highways in Illinois. In addition, the design of the pavement is basically typical of present-day practices, the major difference being that the Vandalia pavements were built directly on the soil subgrade rather than on a stabilized subbase, as is currently being used. The results obtained from the Vandalia pavement when compared to those obtained from the new experimental pavements suggest that minor rusting of the steel at transverse cracks can be expected to develop, but that severe corrosion adversely affecting steel strength and ultimate performance of the pavement should not be a problem.

The analysis of the data relative to design variables and service conditions that conceivably could influence the development of corrosion included crack width, depth of reinforcement, crack spacing, type of reinforcement, pavement age, and traffic load applications. Of these variables, crack width is the only one that appears to have any relationship or influence on corrosion. As indicated in Figure 7, the steel in a greater percentage of the cores exhibited evidences of light to moderate corrosion when the crack width was greater than 1/128 inch. Corrosion existed in 72 percent of the cores from cracks greater than 1/128 inch in width as compared to 40 percent from cracks less than 1/128 inch. The single core of the 151 obtained during the investigation that showed evidence of severe corrosion (Rating 4) came from a crack width that was greater than 1/128 inch. For both cases, however, cores were taken where the steel was completely clear or free of any rust. The results are interpreted as indicating that the potential for corrosion to develop increases as the width of the crack at the level of steel increases. No significant relationships were found to exist between steel corrosion and depth of reinforcement, crack spacing, type of reinforcement, pavement age, or traffic.

The examinations of the crack interfaces showed discoloration or discoloration plus the accumulation of soil fines in the crack for all cores. This is considered indicative of the fact that some water does penetrate transverse cracks in CRC pavement. No evidences of structural distress were found that could be attributable to the fact that some water does penetrate the fine cracks, and in some cases soil fines accumulate. No significant relationship was found between the condition of the crack face and the condition of the steel. The amount of water that percolates through the transverse cracks in CRC pavement is believed to be very minor. This has been borne out in the laboratory where cores removed from the pavements at transverse cracks have been subjected to a 1-inch head of water. The cores taken from typical transverse cracks have never permitted water to fluently pass through the crack. Typically, some dampness at the bottom of the core occurs after extended periods of time.

Pavements in Illinois receive appreciable amounts of deicing salts during winter maintenance, placing them in an environment considered highly conducive to steel corrosion. This fact, combined with the finding that some water does get through the cracks without serious corrosion having developed, suggests that the transverse cracks in adequately performing CRC pavement apparently are tight enough to prohibit sufficient oxygen from getting to the steel to cause a serious corrosion problem. Also, the infiltration of soil fines in cracks that are somewhat open at the surface may be forming a seal to further reduce the amount of air that reaches the steel.

In summary, this study has shown that steel corrosion adversely affecting pavement performance is not now a problem in CRC pavements in Illinois. While the study has not provided definitive proof that steel corrosion will not be a problem in the future, the results from the older Vandalia pavement strongly suggest that it should not be in CRC pavements constructed in accordance with current Illinois design standards.

RECOMMENDATIONS

The present findings indicate that steel corrosion adversely affecting steel strength and pavement performance is not now a problem with Illinois CRC pavements designed and constructed in accordance with present standards. The results obtained from the old Vandalia pavements further indicate that serious steel corrosion should not be a problem in the future with adequately performing CRC pavements. A definite conclusion based on presently available information is considered premature at this time, however, in light of the age of the experimental pavements (4 to 7 years), and the fact that the Vandalia pavement is the only CRC pavement in Illinois that now has a long service life. Thus, it is recommended that a similar investigation be conducted on the experimental pavements after another 5 to 7 years of service to confirm present findings.

While results of this study show no need for changes in design standards relative to steel corrosion, it appears advisable to give consideration to increasing the size of longitudinal reinforcement from No. 5 to No. 6 bars to further guard against the development of serious corrosion and to provide a possible reduction in construction costs. This would reduce the ratio of the steel surface area to its cross-sectional area, making the steel less susceptible to the development of serious corrosion. Also, indications are that mill costs for No. 6 bars are less than those for No. 5 bars and the number of bars to be handled and placed in the field would be reduced, even with some increase in percent of longitudinal reinforcement above 0.6 percent, which should be reflected as a saving in construction costs.

REFERENCES

1. Lindsay, J. D., A Ten-Year Report on the Illinois Continuously Reinforced Pavement: HRB Bulletin 214, p. 22-40, 1959.

2. Burke, John E. and Dhamrait, Jagat S., A Twenty-Year Report on the Illinois Continuously Reinforced Pavement: HRB Record 239, p. 197-211, 1968.

APPENDIX A

SUMMARY OF MEASUREMENTS

TABLE A-1

SUMMARY OF MEASUREMENTS OF CORES REMOVED FROM EXPERIMENTAL PAVEMENTS

Test Site No.	Crack Spacing (ft.)	Type of Steel	Slab Thickness Design (in.)	Slab Thickness Actual (in.)	Steel Depth Design (in.)	Steel Depth Actual (in.)	Crack Width at Steel Level (in.)	Steel Rating	Intrusion of Foreign Material
1	0-1	bars	6	6.0	2	2.5	f	1	no
	0-1	bars	6	b	2	b	b	1	no
	4-5	bars	6	6.0	2	2.5	b	1	no
	4-5	bars	6	b	2	b	b	1	no
	0-1	bars	7	7.5	2	2.8	f	1	no
	0-1	bars	7	7.3	2	2.5	f	1	no
	4-5	bars	7	7.1	2	2.3	f	1	no
	4-5	bars	7	7.1	2	2.6	f	1	no
2	0-1	bars	8	7.8	3	3.0	1/64	1	yes
	0-1	bars	8	8.0	3	2.8	b	1	yes
	4-5	bars	8	8.0	3	3.0	1/64	1	yes
	4-5	bars	8	7.5	3	2.8	f	1	yes
	8-9	bars	8	8.0	3	3.3	1/64	1	yes
3	0-1	fabric	10	9.8	3.5	3.3	1/64	1	yes
	0-1	fabric	10	10.1	3.5	3.4	b	3	yes
	4-5	fabric	10	10.5	3.5	3.3	1/64	2	yes
	4-5	fabric	10	9.8	3.5	2.8	1/64	3	yes
4	0-1	fabric	8	8.5	2	3.0	f	2	yes
	0-1	fabric	8	8.0	2	2.9	f	2	yes
	4-5	fabric	8	8.3	2	2.5	f	1	no
	4-5	fabric	8	8.1	2	3.3	f	2	yes
	8-9	fabric	8	8.5	2	3.1	f	2	yes
	0-1	fabric	8	8.3	3	3.0	f	1	no
	0-1	fabric	8	8.3	3	2.6	f	1	no
	4-5	fabric	8	8.3	3	2.8	f	2	no
	4-5	fabric	8	b	3	b	b	1	no

(continued)

TABLE A-1 (continued)

SUMMARY OF MEASUREMENTS OF CORES REMOVED FROM EXPERIMENTAL PAVEMENTS

Test Site No.	Crack Spacing (ft.)	Type of Steel	Slab Thickness Design (in.)	Slab Thickness Actual (in.)	Steel Depth Design (in.)	Steel Depth Actual (in.)	Crack Width at Steel Level (in.)	Steel Rating	Intrusion of Foreign Material
4 (continued)	8-9	fabric	8	8.3	3	3.0	1/128	2	no
	8-9	fabric	8	8.5	3	2.5	f	1	no
	0-1	fabric	8	8.3	4	3.5	f	1	yes
	4-5	fabric	8	b	4	b	b	1	yes
	4-5	fabric	8	8.0	4	3.6	f	2	yes
	8-9	fabric	8	8.1	4	4.5	f	1	no
	8-9	fabric	8	8.0	4	4.5	f	2	yes
5	0-1	bars	7	7.0	2	2.1	f	2	no
	0-1	bars	7	7.0	2	2.0	f	1	no
	4-5	bars	7	7.3	2	2.3	f	1	no
	4-5	bars	7	7.0	2	2.0	f	2	no
	4-5	bars	7	7.5	3.5	4.0	b	1	no
	4-5	bars	7	7.3	3.5	4.0	b	1	no
	8-9	bars	7	b	3.5	b	b	2	no
	8-9	bars	7	7.3	3.5	3.8	f	1	no
	0-1	fabric	7	7.3	3.5	3.5	f	1	yes
	0-1	fabric	7	7.1	3.5	3.1	1/64	2	yes
	4-5	fabric	7	7.1	3.5	3.0	1/64	1	yes
	4-5	fabric	7	7.0	3.5	3.3	b	1	yes
	8-9	fabric	7	7.4	3.5	3.6	f	1	yes
	8-9	fabric	7	7.2	3.5	3.6	f	2	yes
6	0-1	bars	7	7.0	3	2.5	f	1	no
	0-1	bars	7	7.0	3	3.3	f	2	no
	4-5	bars	7	7.0	3	3.6	f	1	no

(continued)

TABLE A-1 (continued)

SUMMARY OF MEASUREMENTS OF CORES REMOVED FROM EXPERIMENTAL PAVEMENTS

Test Site No.	Crack Spacing (ft.)	Type of Steel	Slab Thickness Design (in.)	Slab Thickness Actual (in.)	Steel Depth Design (in.)	Steel Depth Actual (in.)	Crack Width at Steel Level (in.)	Steel Rating	Intrusion of Foreign Material
6 (continued)	4-5	bars	7	7.0	3	3.9	b	2	no
7	0-1	fabric	7	7.5	3	3.4	b	1	yes
	0-1	fabric	7	7.4	3	3.0	f	1	yes
	4-5	fabric	7	7.8	3	4.0	f	1	yes
	4-5	fabric	7	7.5	3	4.3	f	1	yes
	8-9	fabric	7	7.8	3	4.0	f	1	yes
	8-9	fabric	7	7.8	3	4.5	b	1	yes
8	0-1	bars	7	7.0	3	3.3	f	1	no
	0-1	bars	7	7.0	3	3.3	f	1	no
	4-5	bars	7	7.1	3	3.4	f	1	no
	4-5	bars	7	7.1	3	3.5	f	1	no
9	0-1	bars	7	7.3	3.5	4.5	1/8	2	no
	8-9	bars	7	b	3.5	b	b	1	no
	8-9	bars	7	7.5	3.5	3.7	f	1	no
	12-13	bars	7	7.8	3.5	4.0	f	1	no
	12-13	bars	7	b	3.5	b	b	2	no
	+15	bars	7	b	3.5	b	b	1	no
	+15	bars	7	b	3.5	b	b	2	no
	8-9	bars	8	8.0	4	4.3	b	1	no
	8-9	bars	8	8.6	4	4.5	f	1	no
	12-13	bars	8	b	4	b	b	2	no
	12-13	bars	8	8.5	4	4.5	f	1	no

(continued)

TABLE A-1 (continued)

SUMMARY OF MEASUREMENTS OF CORES REMOVED FROM EXPERIMENTAL PAVEMENTS

Test Site No.	Crack Spacing (ft.)	Type of Steel	Design (in.)	Actual (in.)	Design (in.)	Actual (in.)	Crack Width at Steel Level (in.)	Steel Rating	Intrusion of Foreign Material
9	+15	bars	8	b	4	b	b	2	no
(continued)	+15	bars	8	8.0	4	b	b	1	no
10	0-1	bars	7	7.5	2	2.6	1/64	3	no
	0-1	bars	7	7.1	2	2.5	f	3	no
	4-5	bars	7	b	2	b	b	2	no
	4-5	bars	7	7.3	2	2.5	f	2	no
	8-9	bars	7	b	2	b	b	3	no
	4-5	bars	7	7.3	3.5	3.9	b	3	no
	4-5	bars	7	b	3.5	b	b	1	no
	8-9	bars	7	b	3.5	b	b	1	no
	8-9	bars	7	7.5	3.5	4.0	1/64	2	yes
	12-13	bars	7	b	3.5	b	b	2	no
	12-13	bars	7	7.4	3.5	4.0	1/64	1	yes
	0-1	fabric	7	7.0	2	2.9	f	2	no
	0-1	fabric	7	7.0	2	2.4	1/32	3	no
	4-5	fabric	7	7.3	2	2.9	f	1	no
	4-5	fabric	7	7.3	2	3.5	f	1	yes
	8-9	fabric	7	7.0	2	2.1	1/64	2	no
	8-9	fabric	7	7.3	2	3.0	1/64	3	yes
	0-1	fabric	7	7.3	3.5	3.5	f	2	no
	0-1	fabric	7	7.0	3.5	3.3	3/32	4	no
	4-5	fabric	7	7.5	3.5	3.6	f	2	no
	4-5	fabric	7	7.3	3.5	3.5	1/16	1	yes
	8-9	fabric	7	7.4	3.5	3.8	f	2	yes
	8-9	fabric	7	7.5	3.5	3.8	f	2	yes
	0-1	bars	8	8.3	2	2.3	7/64	3	no

(continued)

TABLE A-1 (continued)

SUMMARY OF MEASUREMENTS OF CORES REMOVED FROM EXPERIMENTAL PAVEMENTS

Test Site No.	Crack Spacing (ft.)	Type of Steel	Design (in.)	Actual (in.)	Design (in.)	Actual (in.)	Crack Width at Steel Level (in.)	Steel Rating	Intrusion of Foreign Material
10 (continued)	0-1	bars	8	8.3	2	3.4	f	2	yes
	4-5	bars	8	8.8	2	3.3	1/64	2	yes
	4-5	bars	8	b	2	b	b	2	no
	0-1	bars	8	8.5	4	4.5	1/64	2	yes
	4-5	bars	8	8.5	4	4.5	1/64	3	yes
	4-5	bars	8	8.5	4	4.5	b	2	yes
	8-9	bars	8	8.5	4	4.5	1/64	1	yes
	8-9	bars	8	8.5	4	4.5	b	3	yes
	12-13	bars	8	8.1	4	4.5	b	2	yes
	12-13	bars	8	8.8	4	4.8	b	3	yes
	0-1	fabric	8	8.3	2	2.5	f	2	yes
	0-1	fabric	8	8.3	2	2.5	f	2	yes
	4-5	fabric	8	8.4	2	2.4	f	1	yes
	4-5	fabric	8	8.8	2	2.6	f	1	no
	8-9	fabric	8	8.6	2	3.0	f	2	yes
	4-5	fabric	8	8.3	4	4.5	f	1	yes
	4-5	fabric	8	8.3	4	4.8	1/32	2	yes
	8-9	fabric	8	8.3	4	4.3	1/64	2	yes
	8-9	fabric	8	8.3	4	4.9	f	2	yes
	12-13	fabric	8	8.3	4	4.9	b	1	yes
	12-13	fabric	8	8.1	4	5.0	f	1	yes
11	0-1	bars	8	8.0	2	2.5	f	1	no
	0-1	bars	8	8.3	2	2.8	f	2	no
	4-5	bars	8	8.3	2	2.6	f	1	no

(continued)

TABLE A-1 (continued)

SUMMARY OF MEASUREMENTS OF CORES REMOVED FROM EXPERIMENTAL PAVEMENTS

Test Site No.	Crack Spacing (ft.)	Type of Steel	Design (in.)	Actual (in.)	Design (in.)	Actual (in.)	Crack Width at Steel Level (in.)	Steel Rating	Intrusion of Foreign Material
11 (continued)	4-5	bars	8	8.1	2	2.9	f	1	no
	0-1	bars	8	8.5	3	3.1	f	2	no
	0-1	bars	8	8.3	3	3.3	f	3	no
	4-5	bars	8	8.0	3	3.5	f	1	no
	4-5	bars	8	8.3	3	3.3	f	1	no
	8-9	bars	8	8.3	3	3.3	f	1	no
	8-9	bars	8	8.1	3	3.5	f	3	no
	0-1	bars	8	8.0	4	4.3	f	2	no
	0-1	bars	8	8.5	4	4.8	1/32	2	yes
	4-5	bars	8	b	4	b	b	2	no
	4-5	bars	8	8.4	4	4.5	f	1	yes
	8-9	bars	8	b	4	b	b	2	no
	8-9	bars	8	b	4	b	b	2	no
	12-13	bars	8	8.1	4	4.5	f	3	no
	12-13	bars	8	b	4	b	b	2	no
12	0-1	fabric	7	7.1	2	3.3	f	1	no
	0-1	fabric	7	7.5	2	3.0	1/64	2	no
	8-9	fabric	7	7.3	2	3.0	b	1	no
	12-13	fabric	7	7.3	2	3.4	f	1	no
	+15	fabric	7	7.3	2	3.1	b	2	no
	+15	fabric	7	7.3	2	3.1	b	1	no
	0-1	fabric	7	7.3	3.5	2.4	f	2	no

(continued)

TABLE A-1 (continued)

SUMMARY OF MEASUREMENTS OF CORES REMOVED FROM EXPERIMENTAL PAVEMENTS

Test Site No.	Crack Spacing (ft.)	Type of Steel	Design (in.)	Actual (in.)	Design (in.)	Actual (in.)	Crack Width at Steel Level (in.)	Steel Rating	Intrusion of Foreign Material
12 (continued)	0-1	fabric	7	7.0	3.5	2.9	b	2	no
	4-5	fabric	7	7.3	3.5	2.1	f	2	no
	4-5	fabric	7	7.3	3.5	3.4	b	2	no
	8-9	fabric	7	7.1	3.5	3.4	f	2	no
	8-9	fabric	7	b	3.5	3.5	b	2	no
	12-13	fabric	7	7.1	3.5	3.5	1/64	2	no
	12-13	fabric	7	7.1	3.5	3.8	1/128	2	no

b - broken core
f - fine hairline crack

TABLE A-2

SUMMARY OF MEASUREMENTS OF CORES REMOVED FROM OLD VANDALIA PAVEMENTS

Test Site No.	Crack Spacing (ft.)	Type of Steel	Design (in.)	Actual (in.)	Design (in.)	Actual (in.)	Crack Width at Steel Level (in.)	Steel Rating	Intrusion of Foreign Material
	0-1	bars	7	7.1	3	3.1	1/64	2	no
	0-1	bars	7	7.1	3	3.1	f	2	no
	4-5	bars	7	8.0	3	3.8	1/32	2	yes
	4-5	bars	7	7.0	3	3.0	1/64	2	no
	8-9	bars	7	7.5	3	4.0	3/64	2	no
	0-1	bars	7	7.3	3	3.3	f	2	yes
	0-1	bars	7	7.3	3	3.4	f	2	yes
	4-5	bars	7	7.5	3	3.5	f	2	yes
	4-5	bars	7	7.3	3	3.3	f	2	no
	8-9	bars	7	7.0	3	3.0	1/64	2	yes
	8-9	bars	7	7.3	3	3.5	f	2	no
	4-5	bars	8	8.0	3	3.3	f	3	no
	4-5	bars	8	b	3	b	b	2	no
	8-9	bars	8	8.0	3	4.0	f	3	no
	8-9	bars	8	8.3	3	3.8	f	3	no
	12-13	bars	8	b	3	b	b	2	no
	12-13	bars	8	8.0	3	3.3	f	3	no
	0-1	bars	8	8.0	3	3.4	f	3	no
	0-1	bars	8	b	3	b	b	3	no
	4-5	bars	8	8.0	3	3.5	f	2	no
	4-5	bars	8	b	3	b	b	3	no
	8-9	bars	8	b	3	b	b	2	no

b - broken core
f - fine hairline crack