CORROSION-RESISTANT DOWEL BARS

Research Laboratory Division
Office of Testing and Research
Research Project 52 G-64
Research Report No. R-591

State of Michigan
Department of State Highways
Lansing, June 1966

CORROSION-RESISTANT DOWEL BARS

This report briefly summarizes the results of laboratory and field studies of dowel bar corrosion under a research project authorized in 1952. The project has been conducted by the Research Laboratory Division in cooperation with the Offices of Design and Maintenance. To date, the project has included four principal phases:

1. Initial review of suggested alternates for structural steel dowel bars and obtaining promising specimens for intensive laboratory evaluation in tests designed to simulate field exposure.

2. Field testing in actual service for dowels passing the preliminary laboratory screening.

3. Additional field testing undertaken seven years after the earlier Phase 2 installation for evaluation of products subsequently entering the market.

4. Additional laboratory testing of materials included in Phase 3, as well as other newer dowel types.

Phase 1: Preliminary Laboratory Study

Results of extensive laboratory studies conducted from the inception of the research project through 1964 were reported in April 1965 in Research Report No. R-497. Dowel descriptions and test results summarized in that report are given in Table 1. The laboratory tests showed that many of the tested dowels, including most painted ones, provided adequate corrosion resistance, but that only a few gave sufficiently good abrasion resistance to warrant consideration for field use. The following types, as Figure 1 indicates, seemed most promising for field exposure in pavement joints:

1. Metallic sleeves of Monel or stainless steel.
2. Nickel plating.
3. Colmonoy fusion coatings.
4. Porcelain enamel sleeves.
5. Vinyl plastic sheathing.
6. Some paint-type coatings, including epoxy, neoprene, and vinyl.

Phase 2: 1957 Field Installation

In 1957, the Department authorized construction of an experimental continuously reinforced pavement on I 96 east of M 66 (34044, C7RN). The experimental pavement was composed of four distinct parts: a) continuously reinforced sections with deformed bar mats, b) continuously reinforced sections with welded wire mesh, c) a standard section with contraction joints spaced at 99 ft, and d) the relief sections at the ends of the continuously reinforced portions.

The six relief sections were each 493 ft long, of 9-in. uniform standard reinforced pavement, with eleven 1-in. expansion joints spaced alternately at 56 ft 3 in. and 42 ft 4 in. Load transfer dowel bars (1-1/4 in. diam, 18-in. long) spaced at 12-in. intervals were clad with corrosion-resistant alloy sleeves to prolong service life and to provide more freedom of movement for the expansion joints in the relief sections. Four of the six relief sections contained one of three types of stainless steel-clad bars (Types 304, 316, or 430) and the remaining two relief sections contained Monel-clad dowel bars. The minimum sleeve thickness for the Type 430 stainless steel-clad bars was 0.015 in., while the Types 304 and 316 stainless steel and the Monel-clad bars had a minimum sleeve thickness of 0.010 in. All the bars were coated with a cutback asphalt and inserted in standard 1-in. expansion joint assemblies prior to installation in the pavement.

In addition, eight consecutive contraction joints in a section of 9-in. uniform standard pavement outside the limits of the continuously reinforced test pavement had standard contraction joint assemblies, containing nickel-coated hot-rolled steel bars. Performance of this section along with that of the 1-in. expansion joints in the six relief sections, was studied as part of the Department's research project on dowel bar corrosion.

On October 27 and 28, 1964 these experimental dowels received their closest inspection in seven years of service. Figures 2, 3, and 4 show typical conditions of dowels in areas of joint opening. A more thorough examination, which should be performed for final evaluation, would require removal of sample dowels from the pavement. The pictures represent the general condition of all dowels in each test series.

Briefly, the inspection indicated that nickel clad dowels, Monel sleeved dowels, and dowels sleeved in three types of stainless steel showed no indication of corrosion, whereas considerable corrosion has taken place in the standard hot-rolled steel dowel bars installed at the same time.

Phase 3: 1964 Field Installation (Chromium-Steel Dowels)

The use of chromium steel for dowel bars was suggested by Bethlehem Steel Co. representatives at a Departmental meeting late in 1962, called to consider possible uses of low-alloy steels in highway work. In the summer of 1964, low-chromium-content alloy steel dowels of a type reported to have good performance potential were installed experimentally in all transverse joints of a 5-mile-long I 196 project in Grand Rapids. Details of this installation were given in Research Report No. R-505 (April 1965). Table 2 gives physical and chemical properties of these dowels, and includes results of tests conducted under contract to the Department by Robert W. Hunt Co., Engineers, of Chicago.

No field evaluation of these dowels was contemplated within the first five years of service, on the assumption that considerable time would be required before severe corrosion would develop, permitting conclusions concerning relative performance. However, to provide data for this report, a quick inspection was made on June 1, 1966, after about 19 months of service. The inspection was limited to dowels in expansion joints adjacent to bridges, because expansion joints at ramp noses, points of curvature, etc., were too tightly closed for sufficient exposure of the dowels. Neoprene sealants in two joints were removed and dowels visually examined and photographed, with the following results for one dowel in each joint:

Sta. 864+35, Passing Lane, Westbound Roadway. The third dowel from the south pavement edge in the first joint west of Bridge X01 of 41027 was examined. The groove width measured 1 in. and the depth to the top of the dowel was 4-1/2 in. from the pavement surface. The bar surface showed very little rust, but small areas of shallow-depth pitting were visible.

Sta. 451+92, Traffic Lane, Eastbound Roadway. The fourth dowel from the south pavement edge in the first joint east of Bridge S16 of 4109 was inspected. The groove width was 1 in., and the depth of embedment to the top of the dowel was 4 in. The bar surface (Fig. 5) was covered with red rust and minor pitting appeared to have occurred.

For purposes of comparison, the evaluation plan for the June 1966 inspection included observation of standard hot-rolled steel dowels on a project immediately west of the experimental chromium steel installation, constructed in essentially the same period and opened to traffic December 14, 1964. This control pavement was Project I 41029A, C35, etc., covering 2.6 miles on I 196:

Sta. 195+92, Traffic Lane, Westbound Roadway. The third dowel from the north pavement edge was inspected. The groove was approximately 1 in. wide, and the depth of the top of the dowel was 4-3/4 in. Figure 6 shows that rusting and pitting of the dowel surface was noticeably more extensive than on the chromium steel dowels.

Phase 4: Supplementary Laboratory Corrosion Study

Bethlehem Steel Co. representatives recommended a 3-percent chromium steel for dowel bars, stating that it eroded at two-fifths the rate of structural steel and pitted only about one-fifth as deep. The premium on such steel would be about 7¢ per lb or 50¢ per dowel.

One would expect an alloy of this type to be somewhat more corrosion-resistant than most structural and low-alloy steels in many types of exposure because of the natural protective oxide coating which chromium develops when exposed to the atmosphere. However, when sample dowels were subjected to an accelerated corrosion test, which consisted of alternate cycles of salt spray, high humidity, and drying in the Laboratory's humidity cabinet, the chromium steel dowel rusted as badly as the uncoated dowels tested, as shown in Figure 7. There is no good explanation for this except that possibly in this particular test corrosive environment, chromium did not offer the corrosion resistance it normally would under many atmospheric conditions.

Six of the metal dowels included in the test rusted, with an increase in diameter ranging from 100 to 16 mils. The lacquer coated dowel developed minor spot rusting, while the nickel plated dowel showed no rusting, as shown in Figure 7. The increase in diameter of the dowels was as follows:

	Increase, mils
Nickel plated	0
Laquer coated (Platon)	0
Malleable iron with copper	40
Chromium alloy*	100
ASTM A 242 corrosion resistant steel (Yoloy-EHS)	40
Galvanized	25
Malleable iron	16

*Chromium content was 3.2 percent by laboratory analysis, checking original test report. On drying, this rust layer was very flaky and non-adhering. These dowels were the type tested on I 196 in Grand Rapids under Phase 3 of this project.

Summary

In view of the data presented, the value of using corrosion-resistant steels for dowel material is questionable from the standpoint of performance and cost.

The limited information presented concerning the use of chromium steel dowels indicates that by the use of such steels, the dowel corrosion problem is not eliminated, but rather deterred.

Since the cost per dowel unit made with chromium steel is approximately the same as for a stainless steel sleeved hot-rolled steel dowel, obviously from the standpoint of the latter's demonstrated superior performance, this type of dowel would have a decided economic advantage, at least until some other cheaper method can be found.

TABLE 1
DOWEL DESCRIPTIONS AND TEST RESULTS

	Sample No.	Description	Corrosion Test Results		Abrasion Test Results				Specimen in Pull-Out, Push-In Tests
			Condition	Rating[a]	Coating Thickness, mils	Coating Resistance, ohms	Abradometer Double Strokes[b]	Resistance to Asphalt	
METALLIC DOWEL AND/OR SLEEVE	53 MR-9	Mayari-R steel alloy[1]	Completely rust-covered with 20-mil increase in diameter	2	--	---	--	--	---
	54 MR-46	Nickel-plated finish	Good resistance; only two pin-hole corrosion points on whole dowel	9	1.5	1,000	10,000[c]	Very good	yes
	55 MR-2	Yoloy EHS steel alloy[2]	Low alloy metal, rust-covered over 4/5ths of surface with 20-mil increase in diameter	3	--	---	--	--	yes
	55 MR-12	Outer chromium case applied by diffusion process	--	-	--	---	--	--	yes
	56 MR-14	Stainless steel, sleeved with No. 430 SS alloy	--	-	12.0	---	--	--	yes
	56 MR-17	Chromium plated	Numerous corrosion pinpoints; rust easily scraped off	7	0.8 to 1.0	---	--	--	---
	56 MR-18	Galvanized steel coating	Quickly developed white corrosion products which increased with exposure	4	6.0	100	2,000	Very good	yes
	56 MR-38	Metallized copper coating	Not tested						
	57 MR-118	Colmonoy fused metallic sleeve (coating appeared dip-applied)	Very good resistance	9	14.0	1,200	17,000[c]	Very good	---
	57 MR-127	Metallic zinc alloy fused sleeve (coating appeared dip-applied)	Fairly good resistance	5-6	11.0	2,000	600	Very good	---
	57 MR-128	Monel sleeves	Very good resistance	9	18.0	1,200	17,000[c]	Very good	---
	57 MR-135	Nickel-plated finish	Very good resistance	9	2.0	1,000	17,000[c]	Very good	---
	57 MR-159	Malleable iron with rattled and shot-blasted finishes	Not tested						
	58 MR-55	Malleable iron containing copper	Not tested						
	64 MR-310	Chromium alloy[3]	No laboratory testing; in test installation on I 196 in Grand Rapids.						
PAINT - TYPE COATING ON STANDARD DOWEL	56 MR-16	Brown paint (2 to 4 mils thick)	Developed numerous small blisters without metallic corrosion under coating. Softened considerably in moist cabinet	6	4.0	20,000	75	Good	yes
	56 MR-26	Proprietary "Platon" varnish (1.5-3.0 mils thick)	Few break-through points; remained hard and scratch resistant in moist cabinet	8	2.0	Infinite	25[d]	Good	yes
	56 MR-75	Zinc-chromate primer (TT-P-636 b type)	Numerous corrosion points	5	6.2	Infinite	25[d]	Good	---
	56 MR-76	MSHD No. 2A primer	No corrosion points	7	--	--	--	--	yes

TABLE 1 (Cont.)
DOWEL DESCRIPTIONS AND TEST RESULTS

	Sample No.	Description	Corrosion Test Results		Abrasion Test Results				Specimen in Pull-Out, Push-In Tests
			Condition	Rating(a)	Coating Thickness, mils	Coating Resistance, ohms	Abradometer Double Strokes(b)	Resistance to Asphalt	
PAINT-TYPE COATING ON STANDARD DOWEL (CONT.)	57 MR-10	Baked-on epoxy paints	--	-	6.0	Infinite	63	Good	---
	-11				7.0	Infinite	63	Good	---
	-12				25.0	Infinite	4,160	Good	---
	-13				11.5	5,000	50	Good	---
	-14				11.0	Infinite	150	Good	---
	-15				8.0	Infinite	100	Good	---
	57 MR-16	Air-dried epoxy paints	--	-	11.0	20,000	50	Fair	---
	-17				11.0	10,000	75	Fair	---
	-18				10.0	50,000	125	Good	---
	-19				9.0	20,000	125	Good	---
	-20				27.0	7,000	225	Fair	---
	-21				15.0	20,000	125	Good	---
	57 MR-119	No. 5A epoxy paint (proprietary)	Very good resistance	9	14.0	Infinite	600	Good	---
	57 MR-123	Black neoprene paint (EC 1706)	Good resistance	7-8	20.0	Infinite	17,000	Good	---
	57 MR-146	Vinyl red lead primer with black topcoats Nos. 20 and 22	Very good resistance	9	28.0	Infinite	11,000	Good	---
	57 MR-157	Uncoated standard dowel (reference dowel)	--	-	--	--	--	--	yes
	57 MR-157a	Subox epoxy (five dowels)	Corrosion dependent on coating thickness (see abrasion test)	5-8	6.0	Infinite	1,450	Good	yes
					9.0	Infinite	8,100	Good	---
					12.0	Infinite	8,100	Good	---
					20.0	Infinite	13,000	Good	---
					21.0	Infinite	9,500	Good	---
	57 MR-157b	Guard rail primer	--	-	6.0	Infinite	30	Good	---
	57 MR-157c	Yellow traffic paint	--	-	14.0	50,000	550	Good	---
PORCELAIN ENAMEL SLEEVE	56 MR-54	Black undercoat about 2 mils thick, enamel overcoat 12 to 15 mils thick	--	-	13.5	Infinite	4,000	Good	---
	56 MR-64	Enamel undercoat about 1.5 mils thick, green enamel overcoat 7 to 8 mils thick	--	-	--	--	--	--	yes
VINYL PLASTIC SHEATH	55 MR-93	Steel sheathed in plastic	Plastic unaffected, but unsheathed ends of steel dowel rusted with 1/4-in. rust creepage inward under plastic	9	33.0	Infinite	36,000(c) (d)	Good	yes

a) Rated on scale where 10 = perfect condition (unaffected by test exposure) and 0 = total failure.
b) Tested dowels corroded quickly in abraded failure-point area after being placed in humidity cabinet.
c) Coating not abraded to failure point.
d) Samples 56 MR-26 and 56 MR-75 tested in dry condition. Sample 55 MR-93 tested partly in dry condition and partly with water used as lubricant in abradometer. All other dowels tested with water lubricant.

1) Analyzing: C-0.10, Mn-0.66, P-0.086, S-0.033, Si-0.30, Ni-0.36, Cr-0.53, Cu-0.56, Mo-trace.
2) Analyzing: C-0.21, Mn-0.87, S-0.027, P-0.066 Ni-0.60, Cr-0.34, Cu-0.51.
3) Analyzing: C-0.20, Mn-0.75, P-0.02, Si-0.27, Cr-3.25.

TABLE 2
PHYSICAL AND CHEMICAL PROPERTIES OF DOWELS

	Constituent	Michigan Specifications	Hunt Co. Samples	
			Lot 31501	Lot 86723
Chemical Composition	Carbon, percent	0.18-0.23	0.22	0.23
	Manganese, percent	0.65-0.90	0.67	0.76
	Phosphorus, percent	0.025 max.	0.007	0.007
	Sulphur, percent	0.025 max.	0.021	0.014
	Silicon, percent	0.20-0.35	0.34	0.25
	Chromium, percent	3.00-3.50	3.03	3.32

	Property	ASTM A-15 Specification		Hunt Co. Samples	
		Intermediate Grade	Hard Grade	Lot 31501	Lot 86723
Physical Properties	Tensile Strength, psi	70,000-90,000	80,000 (min)	156,000	162,000
	Yield Point (min) psi	40,000	50,000	107,250	97,600
	Percent Elongation in 8 in. (min)*	$\frac{1,300,000}{\text{tensile strength}}$ -4%**	$\frac{1,100,000}{\text{tensile strength}}$ -4%	3.75	14.37
	Bond Test, 90°	waived	waived	Satisfactory	Satisfactory

* 1-1/4 in. diam plain bars

** But not less than 12 percent

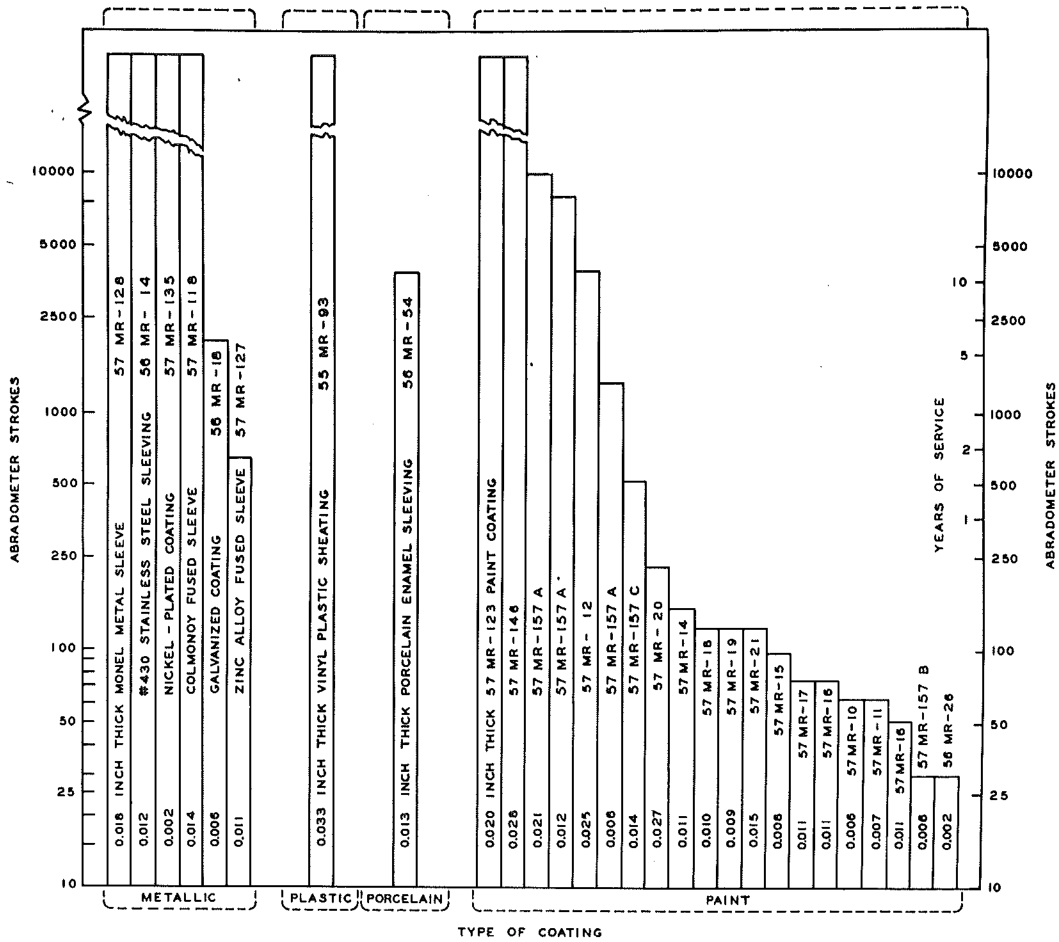

Figure 1. Abrasion resistance of various specimens

Figure 2. Surface condition typical of Monel and stainless steel sleeved dowels. Brown stains do not indicate corrosion.

Figure 3. Typical surface condition of nickel clad dowels.

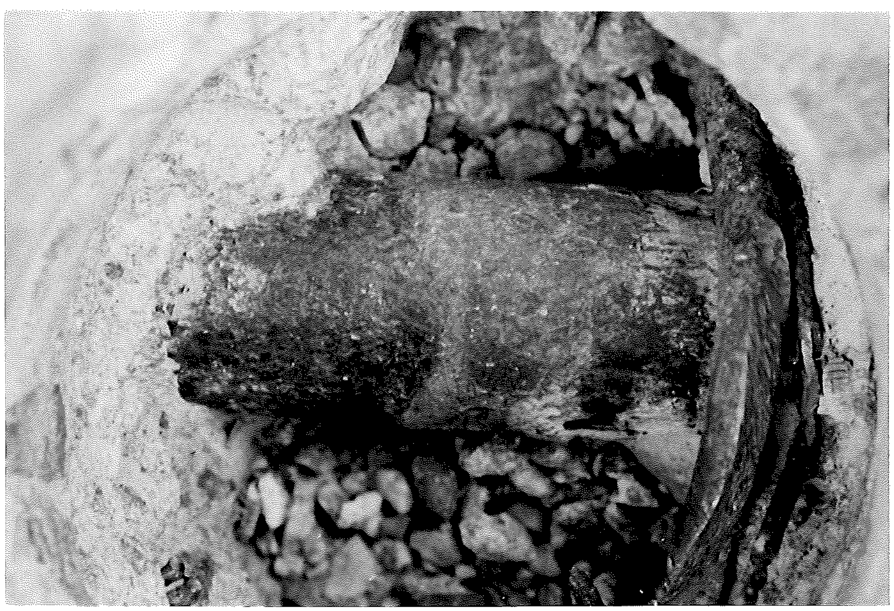

Figure 4. Surface condition of standard dowels; note considerable corrosion.

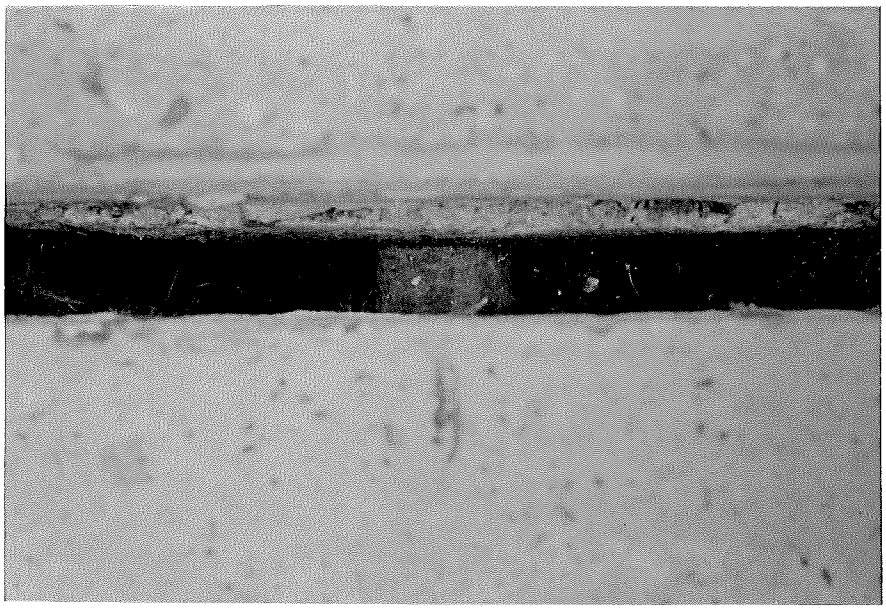

Figure 5. Typical corrosive condition of chromium-steel dowels.

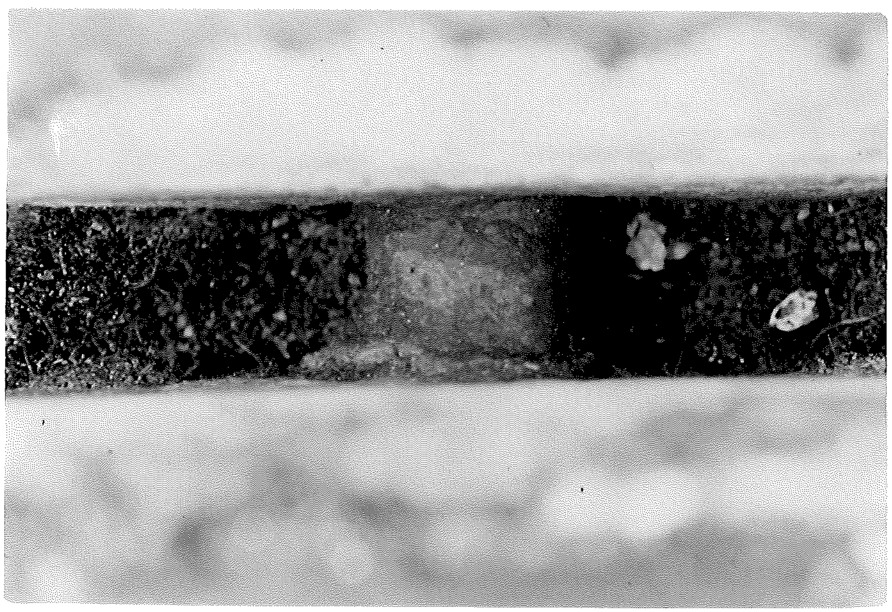

Figure 6. Typical corrosion of standard dowels.

Figure 7. Condition of several dowel materials subjected to accelerated corrosion test.