STUDIES OF CORROSION RESISTANCE OF DOWEL BARS

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In 1952, the Michigan State Highway Department initiated a research project to study the dowel bar corrosion problem, in light of several possible correctives appearing on the market at that time. This problem was recognized as being nationwide, and a useful analysis with suggested solutions had been presented by William Van Breenman of the New Jersey State Highway Department at the Highway Research Board meeting of December 1948.

The Research Laboratory's initial studies and Van Breenman's work indicated that this corrosion often resulted from the fact that customary dowel lubricants, or bond breaking agents, soon wear or wash away and give only short-term corrosion protection to the steel dowel's unbonded portion. When this occurs, the dowel's unbonded portion then rusts and assumes an increased volume. Being confined, the rusted and enlarged dowel exerts a large expansive force and thereby restrains its own movement. Eventually this can yield an immobilized, seized, or "frozen" joint. The expansive force on the concrete surrounding the dowels and immobilization of the joint can lead to stresses that crack the concrete.

Michigan's project study included the following three phases:

1. Reviewing suggested alternates for the structural steel dowel bars and obtaining promising specimens for laboratory evaluation.

2. Evaluating samples in laboratory tests designed to simulate field exposure of the dowels.

3. Arranging field tests, in actual service, for dowels receiving the best ratings in the laboratory tests.

The dowel samples obtained are listed and briefly described in Table 1, grouped in four general categories: a) metal clad, plated, or alloyed dowels and sleeves, b) standard hot-rolled steel dowels with paint-type coatings, c) dowels with porcelain enamel sleeves, and d) dowels sheathed in vinyl plastic. The laboratory identification numbers assigned to these samples indicate that they were procured over a period of several years. Some arrived after others had already undergone particular laboratory tests, and in a few cases test samples were received as single specimens, both of which precluded exposure to all of the tests.

Laboratory Tests

Depending on the quantity of each sample type received for testing and on when they arrived, the dowels underwent one or more of the following tests, designed to duplicate actual service conditions:

1. Cabinet exposure to alternating salt spray and 100-percent humidity.

2. Abrasion testing in an abradometer.

3. Pull-out, push-in tests after partial encasement in concrete, during extended storage in the laboratory's moist room.

Corrosion resistance, under moisture conditions simulating the joint space environment, was determined for most test dowels by exposure in a salt spray (fog) cabinet maintained at 95 F for a period of about 55 days. This test differed from ASTM Designation B 117 (Salt Spray (Fog) Testing) in that it employed an alternating exposure to salt spray and then to 100-percent humidity maintained in the cabinet. This test cycle was used because it was known that one of the large automobile producers used the same modification in determining corrosion resistance of metal accessories such as bumpers, grilles, and handles. The producer's experience showed that this test procedure yielded results more representative of actual service conditions than did the unmodified ASTM test. Results of the cabinet tests are summarized in Table 1, and the condition of some dowels after this exposure is shown in Fig. 1.

Abrasion resistance of the protective coatings was determined by use of an abradometer, fitted with an abrading medium, designed to simulate actual service in the joint space. The abradometer itself (Fig. 2) was an improvised piece of test equipment, fabricated in the laboratory

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 pin-points; 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.

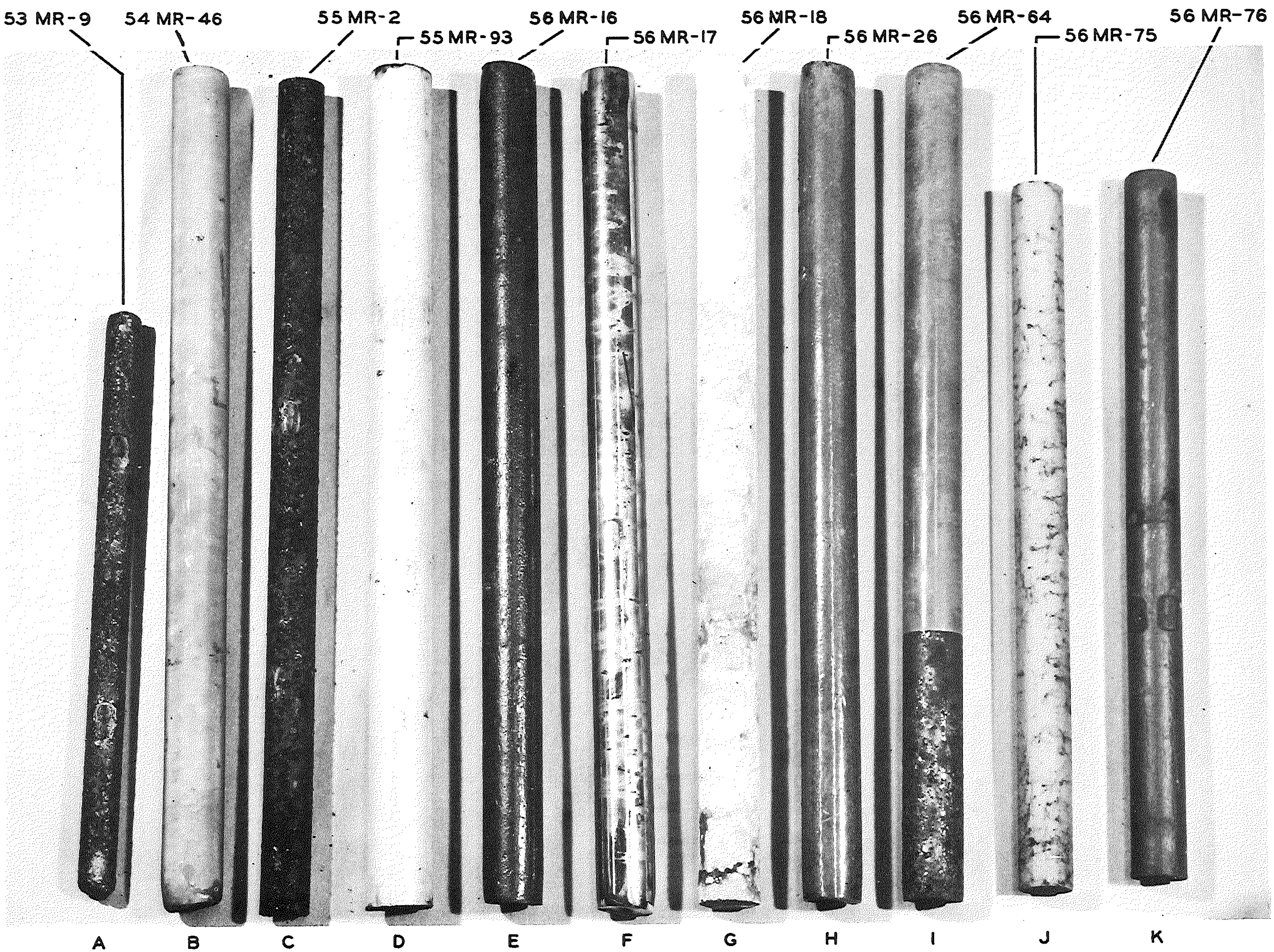

Figure 1. Effects of corrosion test exposure on representative dowel specimens (metallic: A, B, C, F, G; painted: E, H, J, K; vinyl plastic sheathed: D; porcelain enamel sleeved: I).

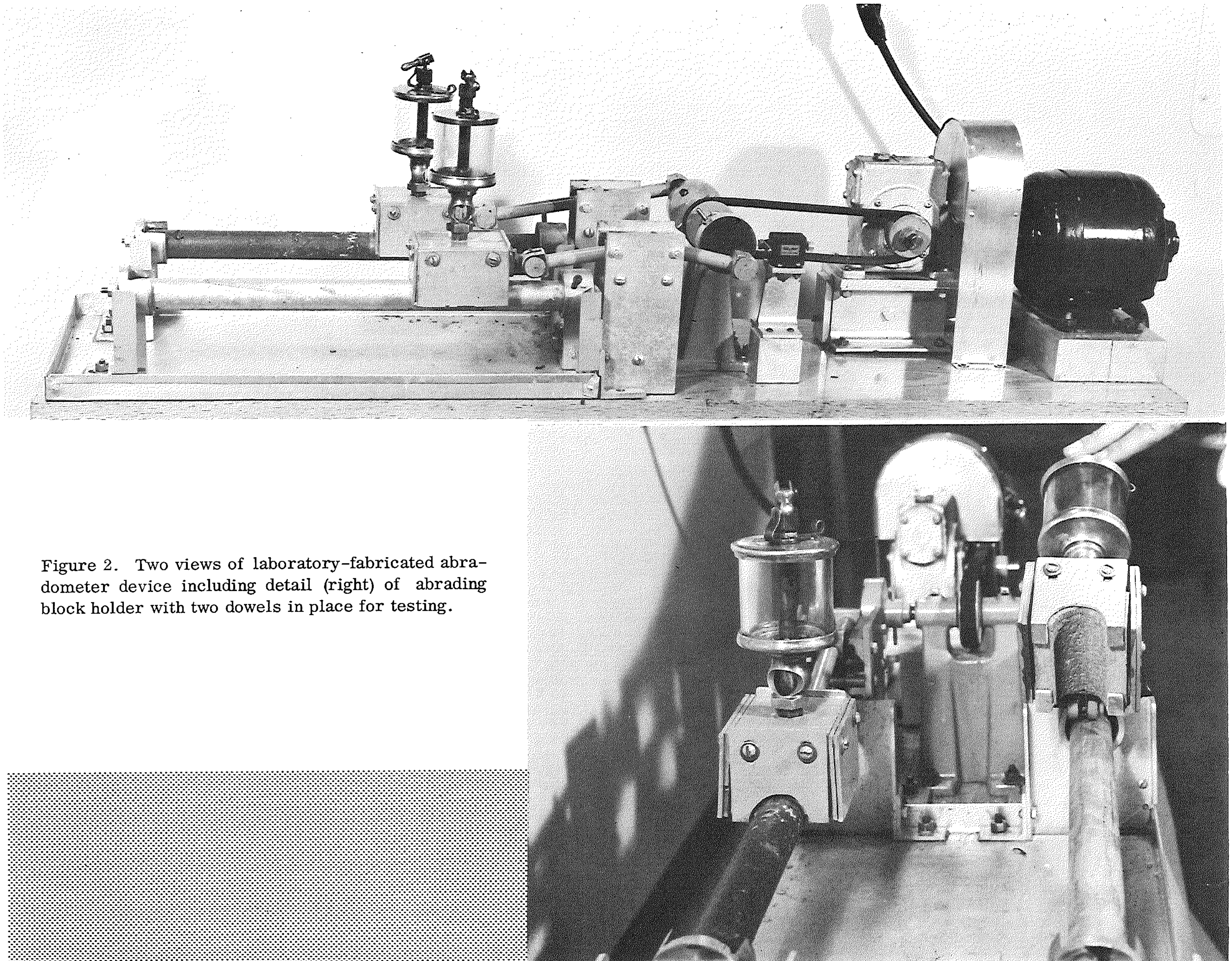

Figure 2. Two views of laboratory-fabricated abradometer device including detail (right) of abrading block holder with two dowels in place for testing.

specifically for this purpose. It operated at 28 double-strokes per minute, utilizing a 2-in. long stroke of a 3.5-in. long abrading block made of portland cement - Ottawa sand (C-109) mortar and cast to fit the test dowel over a circumference area covering an arc of about 120°. The test load used was the 2500-gram weight of the abrading block assembly itself. Dropping-type oilers were fitted into the abrading block holders to permit use of water as a lubricant, since it was noted that use of water during tests tended to keep the abrading block in an unclogged condition, thus yielding faster and more reproducible abrading action. Two dowels could be abraded simultaneously in the apparatus, which was fitted with a counter.

Abrasion test data on the evaluated coatings are also listed in Table 1, including a) coating thickness, b) initial electrical resistance of coating as determined by a continuity tester (on paint-type coatings, this value is considered to be proportional to ability to protect metal bases), c) relative abrasion resistance in terms of total double-strokes of the abrading block required to give an electrical resistance of 2000 ohms across the test coating (failure point), d) whether water was used as lubricant during the test, and e) relative resistance of the coating to softening by an asphaltic bond-break agent.

Relative coating resistance to abrasion is also summarized in Fig. 3. The y-axis has a secondary scale converting abrasion resistance, in strokes, to years of expected unrusted dowel service, on the basis of 365 double-strokes per year.

In addition to these corrosion and abrasion tests, a coat of RC-1 bond break agent was applied to each of eleven representative dowels and allowed to dry. Each dowel was then embedded half its length in a concrete block and after three days of curing the dowels were pulled out 1 in., pushed back, and the forces required were recorded. The encased dowels were then taken to the moist room for extended storage. The pull-out test was repeated at intervals of 10 days, 60 days, one year, and two years after original encasement. Their appearance after nearly six years of moist room exposure is shown in Fig. 4.

It was assumed that periodic recording of force required to pull a dowel would reflect any increase in volume due to corrosion. However, the test failed to indicate any consistent increase or decrease of load that could be correlated with increased time in moist room storage. It was concluded that this testing technique failed to duplicate field conditions, in that the dowel lubricant remained intact, the pull-out tests were infrequent, concrete shrinkage around the dowel was erratic, and the hot-rolled steel dowel surfaces were not true cylinders.

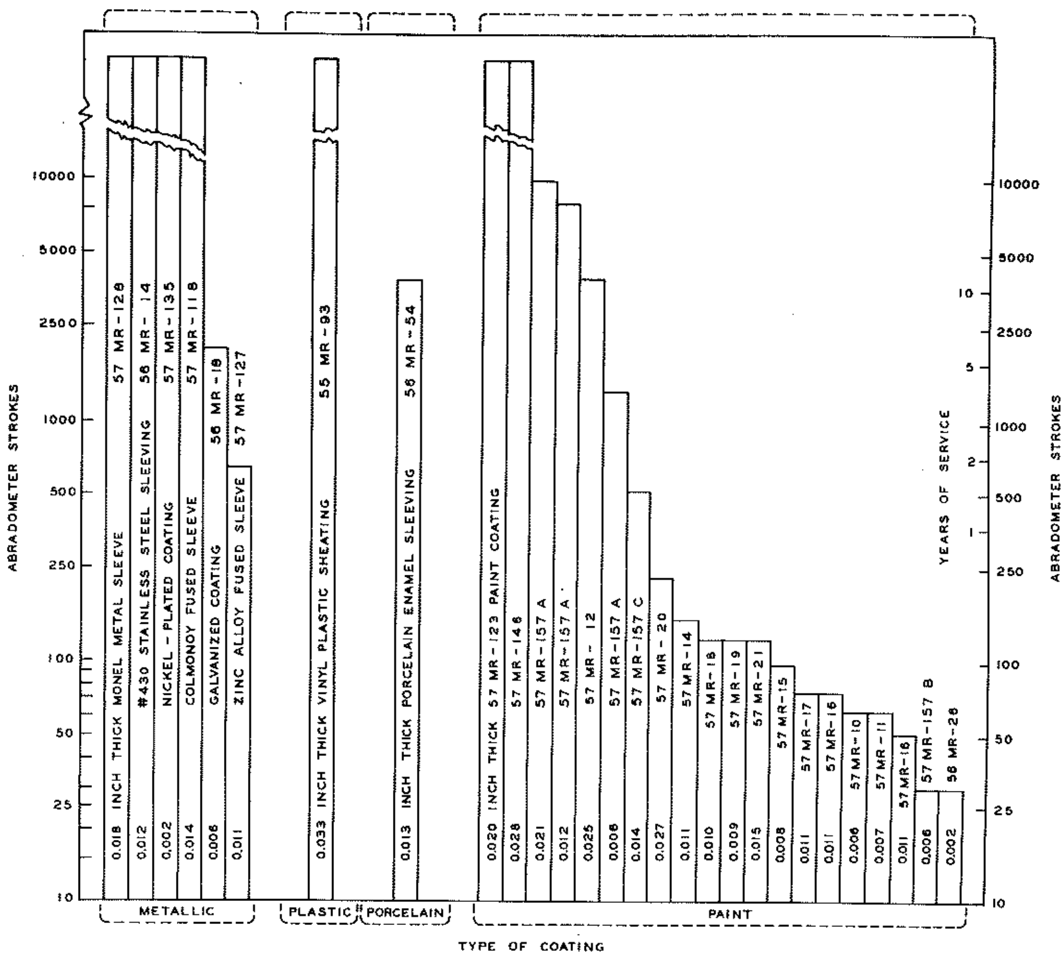

Figure 3. Abrasion resistance of various specimens.

In summary, the laboratory tests showed that many of the tested dowels, including most painted ones, provided adequate corrosion resistance, but that only a few also gave sufficiently good abrasion resistance to warrant consideration for field use. The following types seemed the 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.

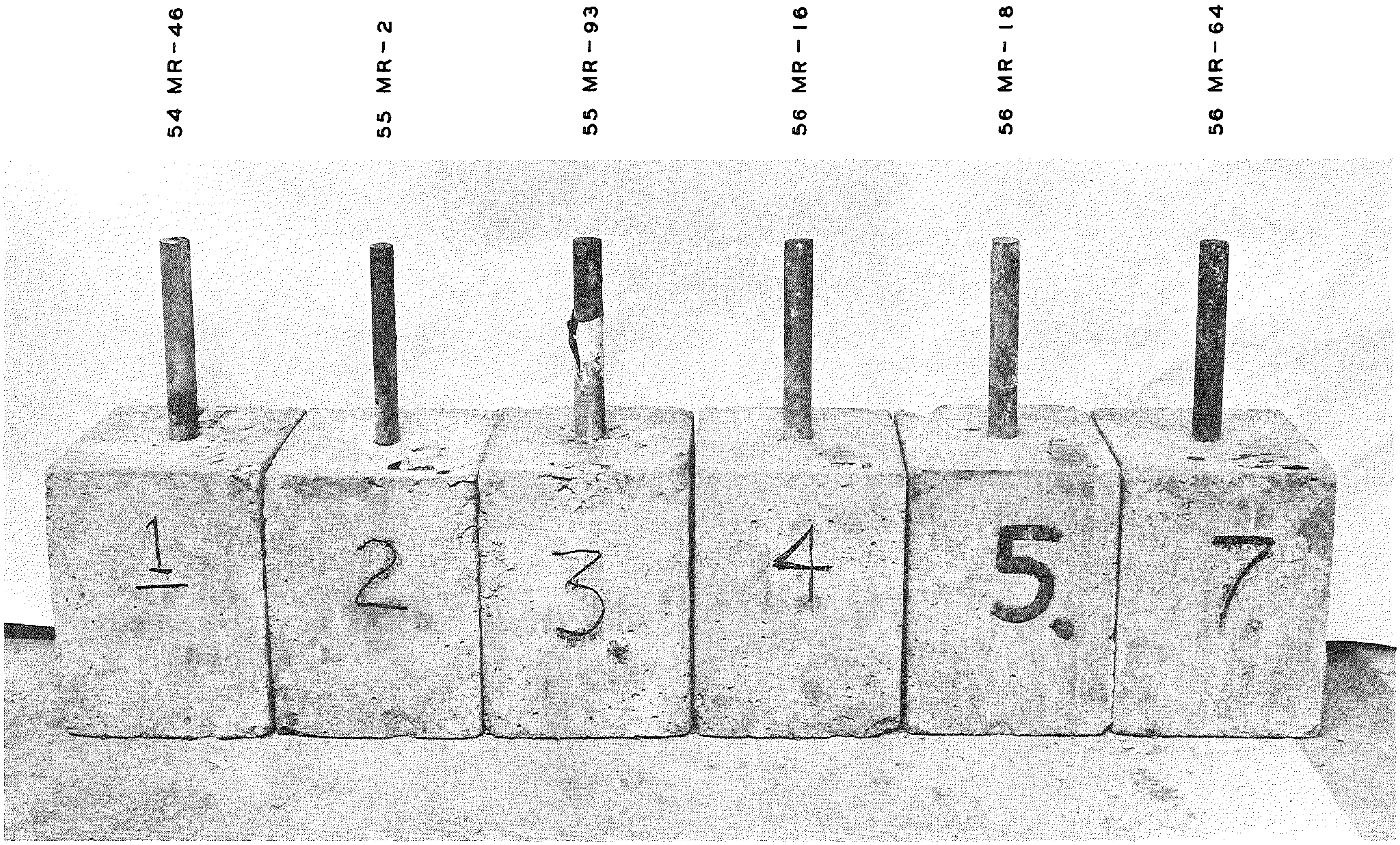

Figure 4. Appearance of corroded dowels encased in concrete for pull-out, push-in tests, after 5-3/4 years of moist room storage. Blocks 1, 2, and 5 contain metallic dowels, Block 3 a vinyl plastic sheathed dowel, Block 4 a painted dowel, and Block 7 a porcelain enamel sleeved dowel.

Field Tests

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 (Fig. 5) 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.

In a thorough field survey on October 27-28, 1964, these experimental dowels received their closest inspection in seven years of service. Figs. 6 and 7 show dowels in open expansion joints with sealant removed prior to resealing. For Figs. 8, 9, and 10, an impact hammer was used to exposed selected dowels of various types in expansion and contraction joints. The inspection indicated that the nickel plated dowels, the Monel sleeved dowels, and dowels sleeved in three types of stainless steel have been superior in durability in this installation to standard hot-rolled steel dowel bars installed at the same time.

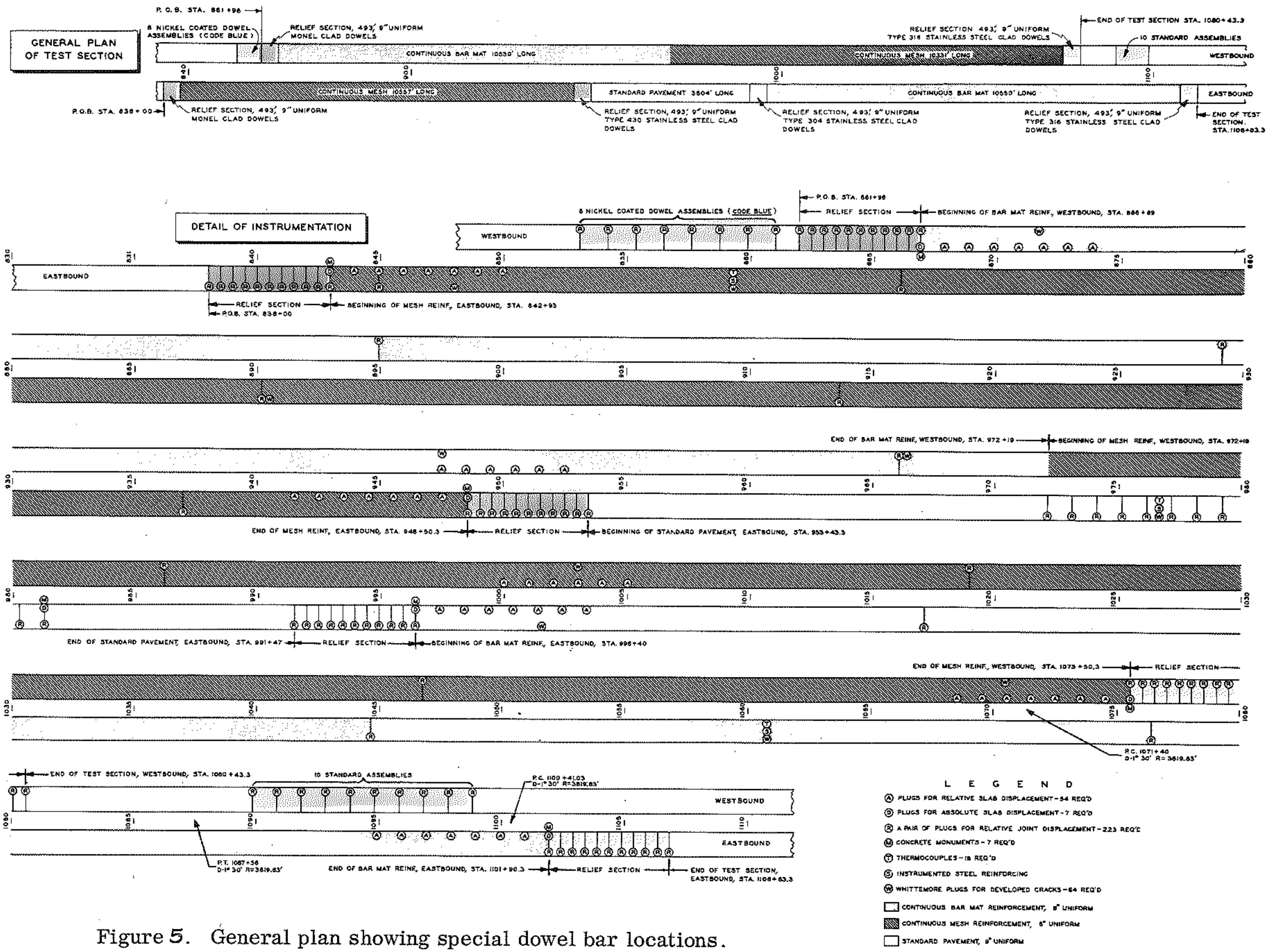

Figure 5. General plan showing special dowel bar locations.

In addition to this I 96 durability experiment, low-chromium-content alloy steel dowels of a type reported to have a good performance potential were installed experimentally in all transverse joints of a 5-mile-long I 196 project in Grand Rapids in 1964. Details of that project are presented in Research Report No. R-505 (April 1965).

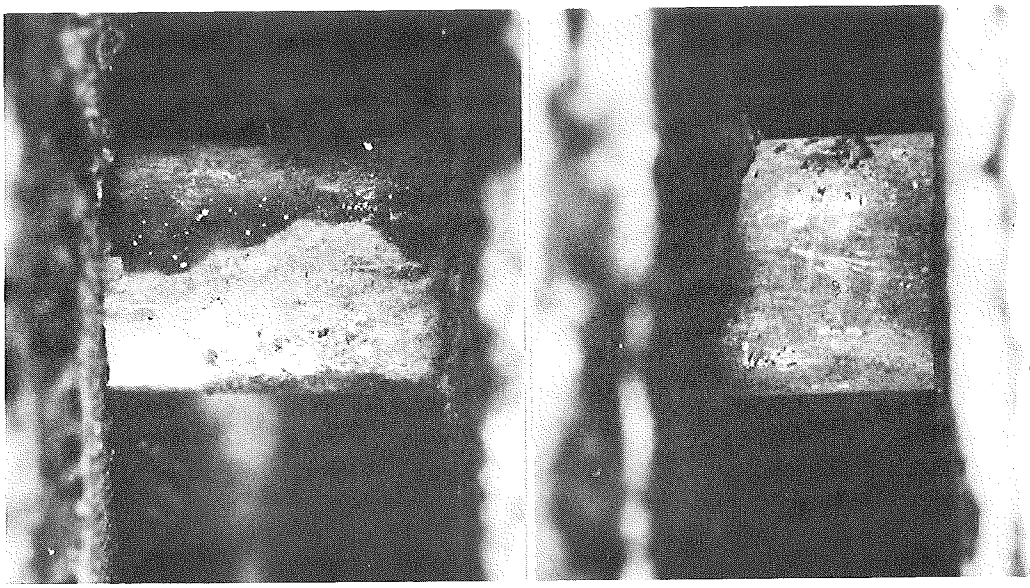

Figure 6. Monel-clad dowels in expansion joints, each typical of a set of six similar dowels in its own assembly and each in excellent condition (left: Sta. 842+92 WB; right: Sta. 866+89 WB).

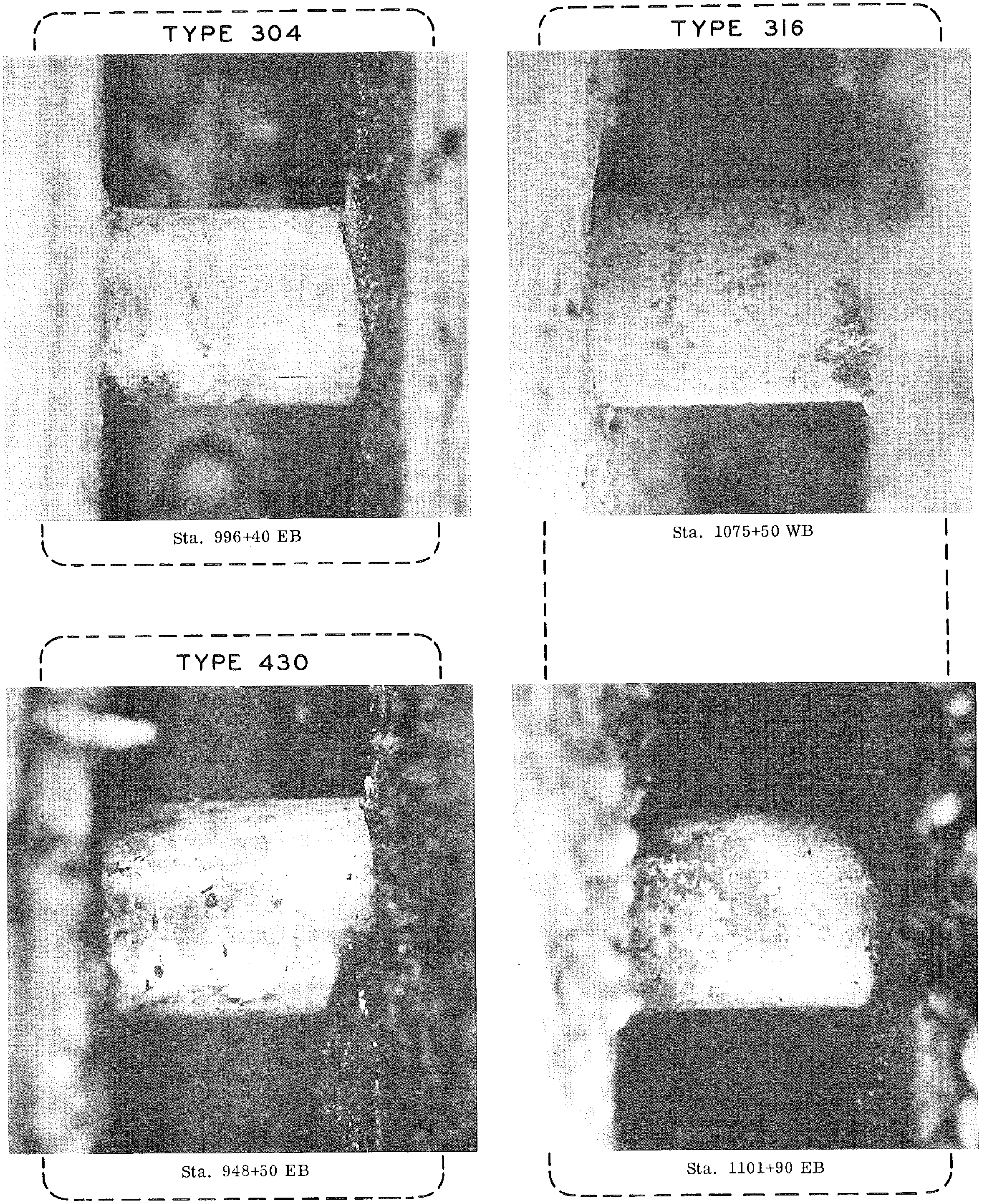

Figure 7. Stainless steel clad dowels in expansion joints, each typical of a set of five to eight in its own assembly, and each in excellent condition.

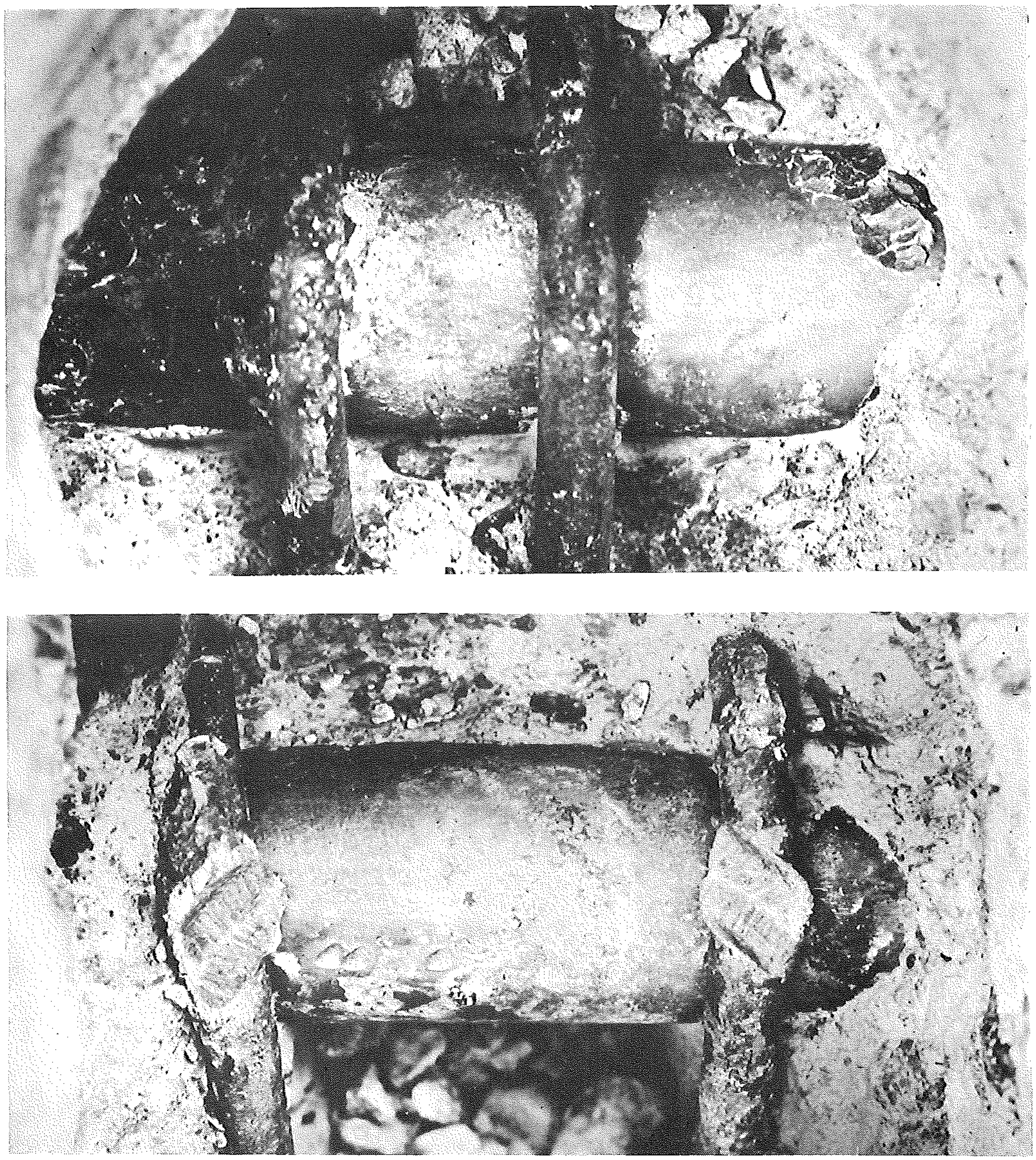

Figure 8. Nickel coated dowels in contraction joints, each typical of two such dowels in its own assembly, and each in excellent condition. Slight indentations in dowels and basket wires caused by impact hammer during excavation (top: Sta. 858+00 WB; bottom: Sta. 856+02 WB).

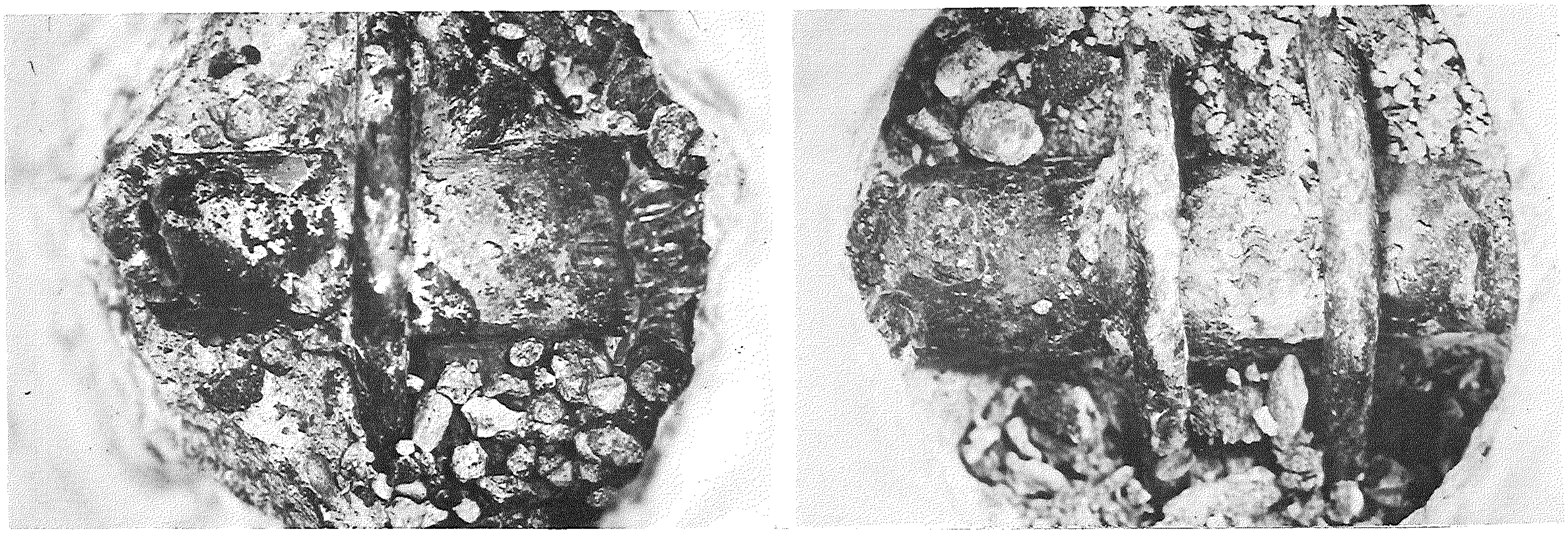

Figure 9 (above). Badly corroded standard hot-rolled steel dowels from one expansion joint assembly (Sta. 1127+30 WB), located first from pavement edge (left) and fifth from pavement edge (right).

Figure 10 (below). Badly corroded standard hot-rolled steel dowels from one expansion assembly (Sta. 1130+00 WB), located first (left) and fifth (right) from pavement edge.