Corrosion Resistance Study of Nickel-Coated Dowel Bars

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In order that a transverse expansion joint in a rigid pavement function properly, it is necessary that the load-transfer dowels offer little resistance to slab movements. Increased use of various salts for ice removal has caused dowel bar corrosion to be of some concern. The products of corrosion from ordinary steel dowel bars exhibit a large volume increase which causes a dowel to "freeze" so that it no longer functions properly. The use of rust-resistant metal coatings on steel dowel bars has shown promise in preventing the development of corrosion products.

This investigation consisted of subjecting ordinary steel dowel bars and varying thicknesses (3, 5, 7, and 10 mil) of nickel-coated dowel bars, embedded in concrete beams, to a soaking-in-brine and drying exposure. Periodically, the force necessary to cause movement of the dowel bars was measured.

Based on the present exposure period, it is evident that a very marked reduction in the force necessary to cause movement of the nickel-coated dowel bars was observed when compared to the uncoated dowel bars.

•CORROSION of load-transfer dowels has been one of the troublesome problems associated with transverse joints in concrete pavement. Dowel corrosion results in restraint to longitudinal movement of the slab followed by pavement failure. Van Breemen (1) concluded in his study of experimental dowel installations in New Jersey that "pavement failures have been due in large measure to deficiencies in joint design." He also found that at practically all of the joints with ordinary hot-rolled steel dowels, there was a progressive development of restraint to changes in dimension. In Van Breemen's study, all of the various dowel coatings, which included red lead, white lead, tar paint, graphite paint, transmission oil, cylinder stock grease, and asphaltic oils, deteriorated so much that they were practically worthless after a short time.

Robert Mitchell (2), in his study of corrosion of load-transfer dowels in Connecticut, found that the nickel-coated dowel appeared to hold considerable promise as a rust-free dowel. At the time when Mitchell released his report, no conclusive evidence of a superior rust-resisting quality between the various nickel coatings used had been noticed.

This report presents experimental laboratory results obtained from accelerated corrosion tests performed on nickel coatings of various thicknesses on 1¼-in. round steel dowels that were embedded in concrete blocks.

The metallurgical characteristics and manufacturing processes for the nickel-coated dowels used in this study are described by Sanborn (3).

EXPERIMENTAL PROCEDURE

It has been observed from previous studies that the corrosion of a dowel results in an increase in its size due to the fact that products of corrosion occupy a much greater

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volume than the original metal. For example:

Sp.G. of iron = 7.87, Sp.G. of Fe_3O_4 (rust) = 5.18

1 cm^3 of iron weighs 7.87 gm

$$\underset{167.55}{\overset{7.87}{3Fe}} + 2O_2 \longrightarrow \underset{231.55}{\overset{X}{Fe_3O_4}} \quad \text{or} \quad 7.87\left(\frac{231.55}{167.55}\right) = 10.95 \text{ gm of } Fe_3O_4$$

$$\text{Volume of } Fe_3O_4 = \frac{10.95 \text{ gm}}{5.18 \text{ gm/cm}^3} = 2.1 \text{ cm}^3 \text{ or a volume increase of over } 100\%$$

This volume increase exerts tremendous pressure on the surrounding concrete and accounts for the development of restraint to longitudinal movement. With these observations in mind, the specimens for evaluating the various nickel coatings were formulated.

A specimen consisted of a 6- by 6- by 12-in. concrete block with the steel dowel bar running lengthwise through the center of the block. The dowel bar extends approximately 5 in. from one end and 1 in. from the other end of the concrete block. A total of 25 specimens were fabricated. Five contained dowel bars with a 3-mil nickel-coating thickness, five with a 5-, 7-, and 10-mil thickness, and five contained ordinary steel dowel bars.

The concrete used in making the specimens contained a well-graded Delphi dolomite, coarse, crushed aggregate with a maximum size of 1 in. and local western Indiana concrete sand. The 28-day compressive strength of the concrete was 4,185 psi. An air-entraining agent was used to improve the durability of the concrete, and its use resulted in a concrete with an air content of 4.5 percent.

A rectangular steel soaking tank containing a brine solution and a storage rack (Fig. 1), which stores 36 concrete specimens, were constructed for this project. The steel rack was used so the specimens could be easily raised and lowered into the brine solution. The soaking tank was constructed of ¼-in. steel plate, and the inside surfaces were coated with coal tar epoxy mastic to prevent corrosion of the tank. The tank is 2 by 6½ ft and is 3½ ft high.

A sodium chloride content of 27,000 ppm was established for the brine solution. This soultion remained at room temperature, which is approximately 80 F.

Two concrete specimens were made in each 6- by 30-in. mold (Fig. 2) with the center 6-in. section remaining empty. The dowel bars were lightly greased with Stanabar grease No. 2 before being placed in the concrete to prevent bonding with the concrete. The molds were stripped from the beams after a 24-hr period. The specimens were then placed in a standard moist room for 27 days. This moist room had a relative humidity of 100 percent and a

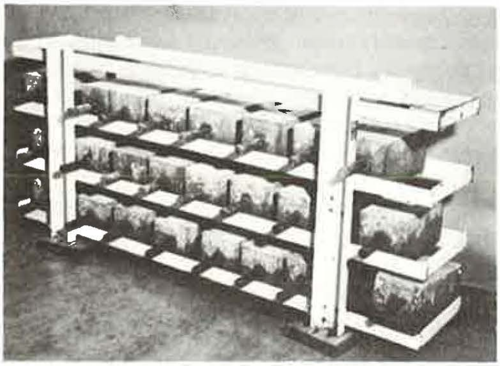

Figure 1. Storage rack.

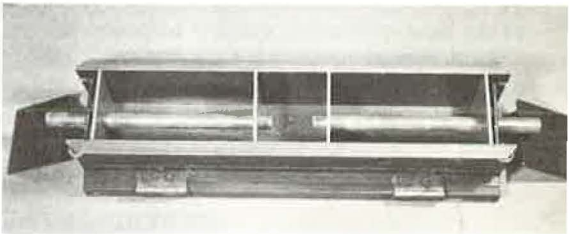

Figure 2. Mold used in making concrete blocks containing nickel-coated dowel specimens.

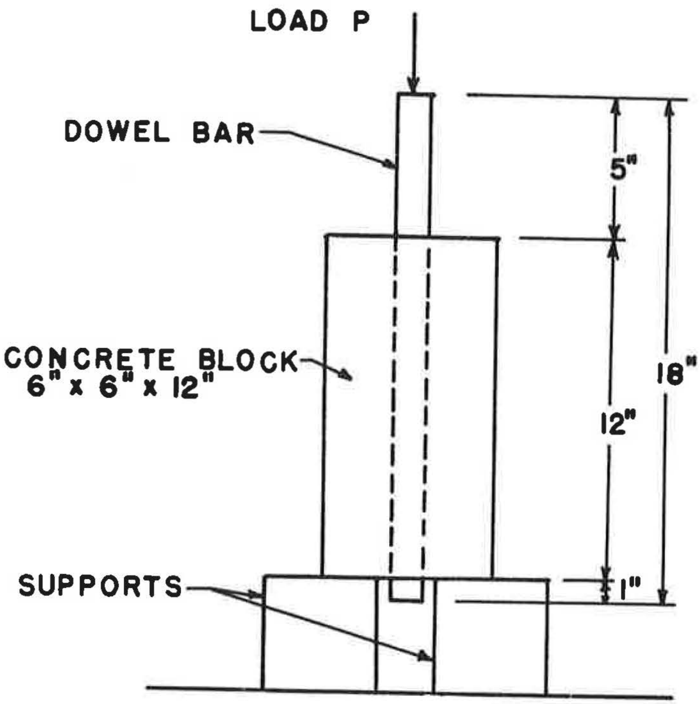

Figure 3. Loading arrangement of push-out test.

temperature of 75 F. At the end of 27 days, the specimens were removed from the moist room and placed on the rack in preparation for the brine exposure. This exposure consists of a 16-hr soaking and an 8-hr drying cycle. At the end of each 50-cycle period, a "push-out" test was performed. The push-out test consisted of applying a load to the protruding dowel in the concrete block and forcing the dowel through the concrete block (Fig. 3). The maximum load required to move the dowel was recorded as a measure of the amount of corrosion formed on the dowel. At the beginning of the test, or at "zero cycles," very little effort was necessary to move the dowels because they were not bonded to the concrete block and corrosion had not yet taken place.

STATISTICAL ANALYSIS

In order to find if there were any differences between dowel groups with different thicknesses of nickel coating, a statistical approach involving the "t" test was used because of the overlap of the results between groups. From statistics, a typical distribution of a normal population could be taken as the t-distribution (Fig. 4a). In this particular study, the populations are the maximum loads required to cause dowel bar movement in each specimen of the different groups. In other words, if a large number of dowel bar specimens with a certain nickel-coating thickness were tested, the resulting maximum loads required to cause dowel bar movement in the specimen would probably be distributed in the form of a t-distribution. Most specimens in the group would tend toward a certain average maximum load. Although there is always the possibility that certain maximum loads are much higher or lower than the average maximum load, this possibility gets smaller as the load differs from the average.

The maximum loads of each specimen group with different nickel-coating thicknesses may be represented by a t-distribution. In most cases these distributions overlap one another (Fig. 4b). Therefore, it is necessary to perform a statistical test to see if two specimen groups are truly different from one another. Since a

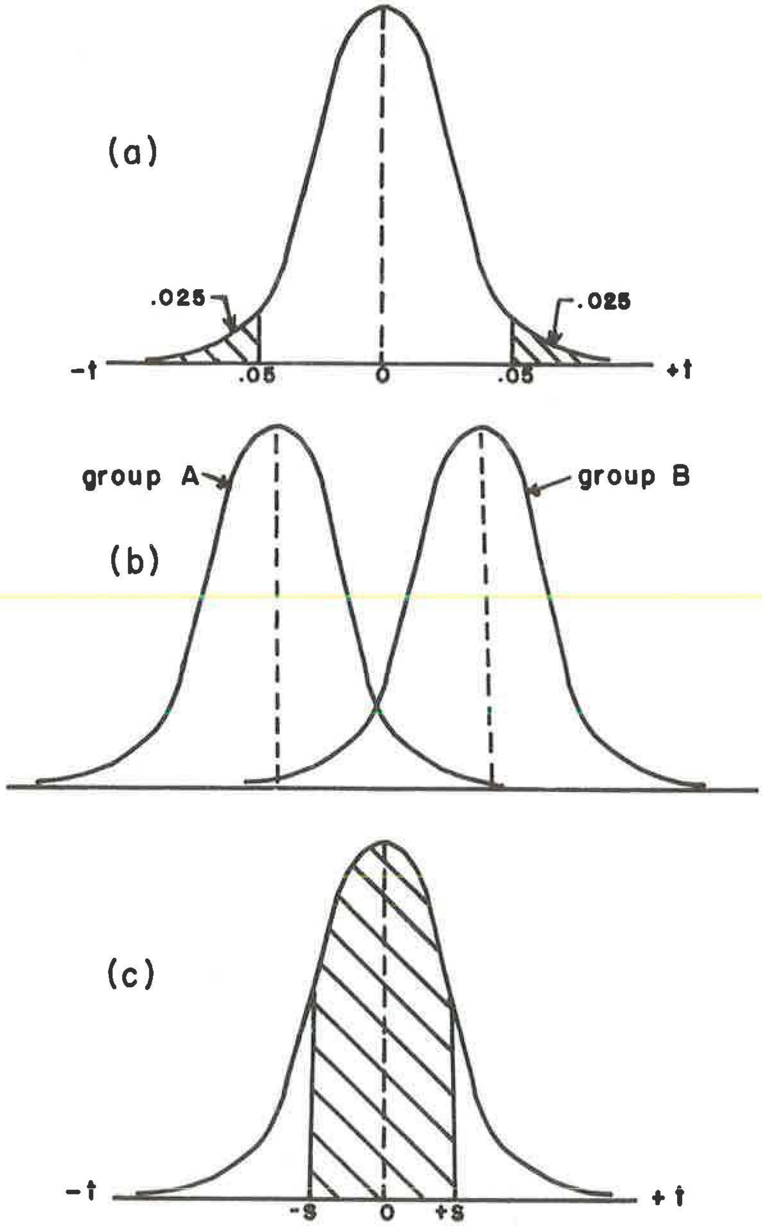

Figure 4. (a) t-distribution with (n - 1) degrees of freedom; (b) t-distribution of two overlapping groups; and (c) shaded area includes 68 percent of total area under t-distribution curve.

t-distribution has been assumed, the statistical test used in this case is called the t-test.

Essentially in performing the t-test, one tries to compare the true mean values of the two groups. The true mean value is not necessarily equal to the average of the maximum loads in each group. The average value of the group is located at the maximum ordinate of the t-distribution curve, but the location of the true mean value for the group on the t-distribution curve is not known at this moment.

If it is assumed that two random samples were obtained from two normal populations (t-distribution) and that the two populations have a common variance, it can be shown that Eq. 1 follows the t-distribution curve.

$$t = \frac{\bar{Y}_1 - \bar{Y}_2}{\sqrt{\frac{S^2}{N_1} + \frac{S^2}{N_2}}} \tag{1}$$

in which

$\bar{Y}_1$ = average maximum load of group 1;
$\bar{Y}_2$ = average maximum load of group 2;
N_1 = number of specimens in group 1;
N_2 = number of specimens in group 2;
S^2 = square of the pooled estimate of the common sample variance; that is,

$$S^2 = \frac{\sum_{i=1}^{N_1} (Y_{1i} - \bar{Y}_1)^2 + \sum_{j=1}^{N_2} (Y_{2j} - \bar{Y}_2)^2}{N_1 + N_2 - 2} \tag{2}$$

Y_{1i} = maximum load on each specimen of group 1;
Y_{2j} = maximum load on each specimen of group 2; and
$N_1 + N_2 - 2$ = degrees of freedom.

It should be noted that in this analysis the sample variances of the two groups are not equal as was assumed in arriving at Eqs. 1 and 2. However, these equations are still used because the statistical analysis is greatly simplified. The sample variance of each group may be calculated using Eq. 3.

$$S^2 = \frac{\sum_{i=1}^{N} (Y_1 - \bar{Y})^2}{N - 1} \tag{3}$$

The standard deviation s of the group is equal to the square root of the sample variance S^2 of the group (Eq. 3). The standard deviation may be used as a measure of the scatter of the data. An interval of plus and minus one standard deviation from the mean would include 68 percent of all the possible values of the maximum loads on the specimens in each group (Fig. 4c).

The calculated t gives an indication of the location of the mean values of the two groups. By use of a table of the percentage points of the t-distribution taken from any statistics book, it may be stated with what percentage certainty the true mean values of the two groups differ. For example, with a t-value of 2.306 and 8 degrees of freedom, a table of percentage points of the t-distribution would show a value of five percent.

This would mean that one would be 95 percent certain that the two groups are different.

RESULTS

The averages of the maximum loads necessary to cause slippage on the five identical specimens of each group for the various exposure periods are given in Table 1 and shown in Figure 5. Table 1 also contains the standard deviation for each set of data.

Table 2 summarizes the sample variances S^2 between groups that are needed in calculating the percentage points of the t-distribution between groups which are indicated in Table 3. All of the necessary calculations were performed as outlined in the preceding paragraphs, and sample calculations are in the Appendix.

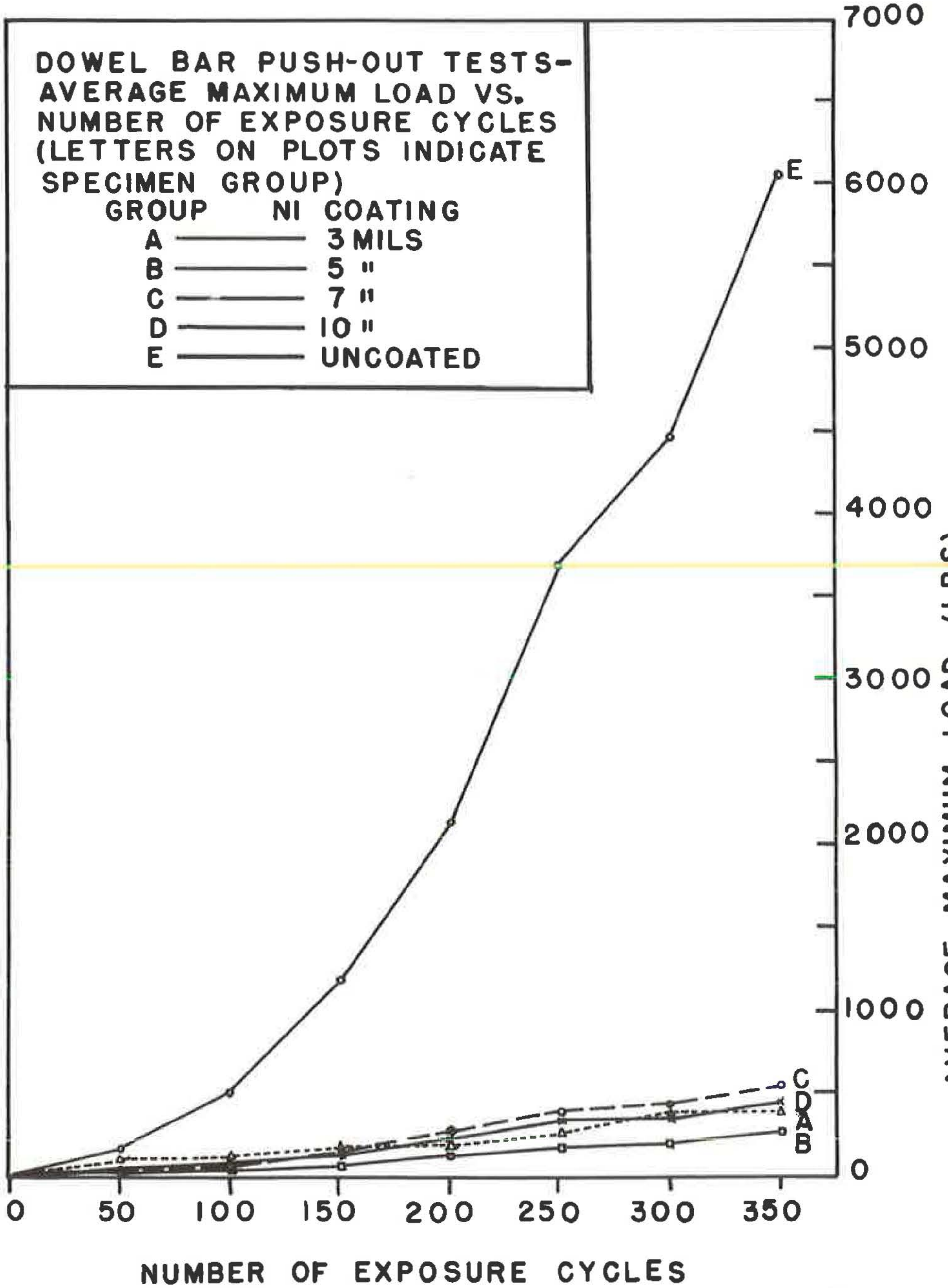

Figure 5.

Photographs of the different specimens were taken at the end of 50 and 350 exposure cycles (Fig. 6). The 3- and 5-mil nickel-coated dowels at the end of 50 exposure cycles appear to be rust-free, but the untreated dowels are obviously corroded. At the end of 350 exposure cycles, a rust spot was evident on the 3-mil nickel-coated dowel; no corrosion was evident on the 5-mil nickel-coated dowel; and considerable corrosion was evident on the untreated dowels.

TABLE 1

AVERAGE MAXIMUM LOAD (LB) NECESSARY TO FREE THE DOWEL BAR IN THE PUSH-OUT SPECIMENS, AND STANDARD DEVIATION OF EACH GROUP

No. of Cycles	Group A (3-mil Ni)		Group B (5-mil Ni)		Group C (7-mil Ni)		Group D (10-mil Ni)		Group E (untreated)	
	Avg.	s	Avg.	s	Avg.	s	Avg.	s	Avg.	s
50	76	33.6	23	7.8	37	10.8	42	21.3	186	51
100	115	37.0	40	9.3	72	11.6	88	32.4	506	134
150	168	52.0	71	26.0	150	40.5	156	36.6	1,184	365
200	200	56.9	114	31.1	250	106.0	217	20.8	2,139	854
250	260	87.8	185	31.0	373	135.5	320	23.8	3,680	1,458
300	365	157.5	208	49.8	416	197.0	349	51.3	4,446	1,444
350	400	181.0	271	49.2	570	243.0	432	42.4	6,042	2,700

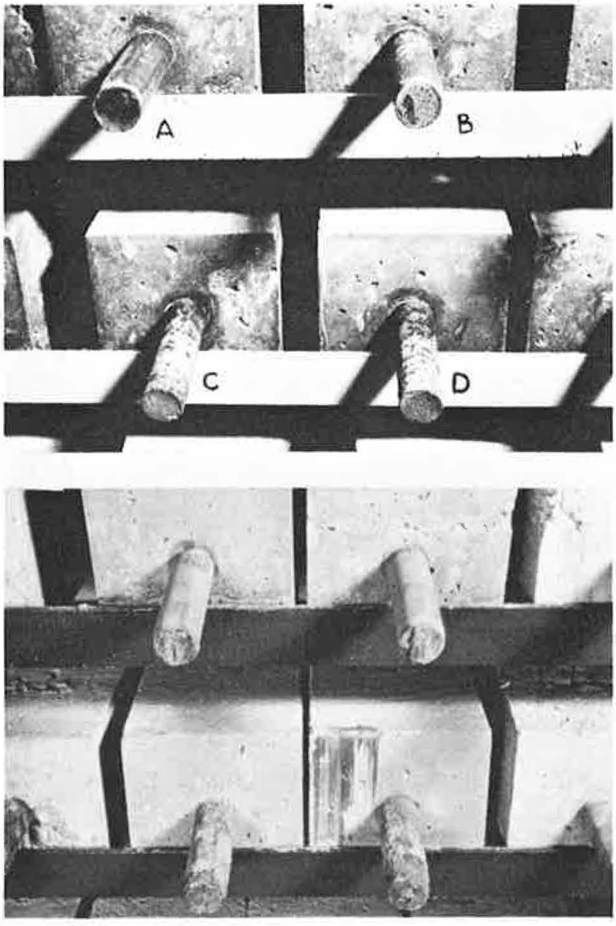

Figure 6. Dowel specimens (a) at end of 50 exposure cycles and (b) at end of 350 exposure cycles. Specimen A—5-mil nickel coating, B—3-mil coating, C and D—untreated.

TABLE 2

SAMPLE VARIANCE S^2
BETWEEN GROUPS OF TABLE 1

No. of Cycles	A & B	B & C	C & D	A & C	A & D
50	616	90	309	692	787
100	861	110	657	896	1,246
150	1,831	1,156	1,470	2,245	2,020
200	2,265	6,109	5,071	6,671	1,835
250	4,812	9,674	8,204	12,282	4,133
300	15,274	20,635	18,121	30,824	13,744
350	19,763	30,779	26,372	44,085	17,259

This is a continuing study and it will be carried on until no further useful purpose is served. Additional information will be reported as it is obtained and evaluated.

TABLE 3

STATISTICAL INFERENCES OF GROUP DIFFERENCES BASED ON PERCENTAGE POINTS OF THE t-DISTRIBUTION

No. of Cycles	A & B	B & C	C & D	A & C	A & D
50	2%	10	—	10	10
100	1	1	40	10	10
150	5	5	—	—	—
200	5	—	—	40	—
250	20	5	50	20	20
300	20	10	50	—	50
350	25	10	30	30	—

Discussion of Results

The conclusions reported herein are based on an accelerated, laboratory-controlled, exposure study. Nevertheless, it is believed that the same relative differences between the coated and the uncoated dowel groups should be obtained from long-time field exposures.

The various groups of dowels with the different thicknesses of nickel were very much alike throughout the study and the groups changed relative positions among themselves between exposure periods. Group E (Fig. 5), with no nickel coating, required the greatest effort by far to cause movement of the dowels. Even the thinnest nickel coating displayed greatly increased corrosion resistance and thereby appreciably reduced interference with freedom of movement of the dowel bars.

Results obtained to date on the nickel-coated dowels are within such a narrow scatter band that the relative merits of the coating thicknesses are not evident at this time.

REFERENCES

1. Van Breemen, W., "Experimental Dowel Installations in New Jersey." HRB Proc., Vol. 34 (1955).
2. Mitchell, R. G., "The Problem of Corrosion of Load Transfer Dowels." HRB Bull. 274, 57-69 (1960).
3. Sanborn, C., "Nickel-Coated Dowel Pins Exposed in Tidal Zone Harbor Island, North Carolina." Highway Research Record 31 (1963).

Appendix

SAMPLE CALCULATIONS

Data at the end of 50 exposure cycles
Maximum loads required to cause dowel bar movement:

Group A	Group D
86 lb	70 lb
44	18
117	43
39	53
94	24

Sum of 5 specimens in group A = 380
Average maximum load of group A = $\frac{380}{5}$ = 76 lb

Sum of 5 specimens in group D = 208
Average maximum load of group D = $\frac{208}{5}$ = 42 lb

Standard deviation s of group A

$$S^2 = \sum_{i=1}^{n} \frac{(Y_1 - \overline{Y})^2}{n-1}$$

in which

n = number of specimens in group
n-1 = degrees of freedom
Y_1 = maximum load on specimen
$\overline{Y}$ = average maximum load for group

$$\begin{aligned}(86 - 76)^2 &= 100\\ (44 - 76)^2 &= 1,024\\ (117 - 76)^2 &= 1,681\\ (39 - 76)^2 &= 1,369\\ (94 - 76)^2 &= \underline{324}\end{aligned}$$

$$\sum_{i=1}^{n} (Y_1 - \overline{Y})^2 = 4,498$$

$$S^2 = \frac{4,498}{5-1} = 1,124.5$$

Standard deviation of group A = s = $\sqrt{1,124.5}$ = 33.6

Sample variance S^2 between groups A & D

$$S^2 = \frac{\sum_{i=1}^{n_1} (Y_{1i} - \overline{Y}_1)^2 + \sum_{j=1}^{n_2} (Y_{2j} - \overline{Y}_2)^2}{n_1 + n_2 - 2}$$

in which

n_1 = number of specimens in group A
n_2 = number of specimens in group D
$n_1 + n_2 - 2$ = degrees of freedom of system

For group A (see previous calculations):

$$\sum_{i=1}^{n} (Y_1 - \bar{Y})^2 = 4,498$$

For group D (similar to calculations for group A):

$$\sum_{j=1}^{n} (Y_j - \bar{Y})^2 = 1,806$$

Sample variance between groups A & D:

$$S^2 = \frac{4,498 - 1,806}{5 + 5 - 2} = 787$$

t-test

$$t = \frac{Y_1 - Y_2}{\sqrt{\frac{S^2}{n_1} + \frac{S^2}{n_2}}}$$

in which

$\bar{Y}_1$ = average maximum load of group A
$\bar{Y}_2$ = average maximum load of group D
S^2 = sample variance between groups A & D
n_1 = number of specimens in group A
n_2 = number of specimens in group B

All terms in the formula for t having been calculated previously:

$$t = \frac{76 - 42}{\sqrt{\frac{787}{5} + \frac{787}{5}}} = 1.93$$

From a table for the percentage points of the t-Distribution (reference: Ostle, "Statistics in Research")

For a system with 8 degrees of freedom ($n_1 + n_2 - 2$)
At a percentage point of 5%, t = 2.306
At a percentage point of 10%, t = 1.860

Therefore in this case where t = 1.93 the percentage point lies between 5% and 10%, or at a maximum of 10%.