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COOPERATIVE HIGHWAY RESEARCH PROGRAM
REPORT 67-6

Alkali Reactivity Of Carbonate Rocks In Missouri

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MISSOURI STATE HIGHWAY DEPARTMENT
BUREAU OF PUBLIC ROADS

ALKALI REACTIVITY
OF
CARBONATE ROCKS IN MISSOURI

Prepared by

MISSOURI STATE HIGHWAY DEPARTMENT

Division of Materials and Research

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in cooperation with

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The opinions, findings, and conclusions expressed in this publication are not necessarily those of the Bureau of Public Roads.

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SUMMARY

The objectives of this study were to determine: (1) the location, description, and degree of reactivity* of the reactive carbonate rocks being used in concrete; (2) the relationship between the expansion of rock prisms and the amount of insoluble matter, and dolomite; and (3) information concerning the desirable length of the rock prism test.

The results of tests on rock prisms from 1152 ledges representing 38 geological formations** indicate that:

1. Some of the ledges in 20 of the 38 geological formations tested exhibited some reactivity (0.05 percent or greater expansion in 8 weeks) to alkali.
2. One hundred twelve (9.7 percent), sixty-eight (5.9 percent), thirty-eight (3.3 percent), twenty-seven (2.3 percent), and twenty-one (1.8 percent) showed expansions in the eight week prism test of or in excess of 0.05, 0.10, 0.20, 0.30, and 0.50 percent respectively.
3. Forty-nine of 897 samples receiving preliminary approval for use in concrete exhibited expansions in the prism test of or in excess of 0.05 percent.

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* Throughout this report "reactivity" refers to the alkali-carbonate reaction resulting in physical expansion of rock.

** The term, "geological formations", is used in this report as a general discription, because much of our stone is sampled by groups of formations and cannot be broken down by the member formations.

Forty-nine (5.5 percent), thirty-two (3.6 percent), twenty (2.2 percent), fourteen (1.6 percent), and eleven (1.2 percent) of the 897 samples showed expansions in the eight week prism test of or in excess of 0.05, 0.10, 0.20, 0.30, and 0.50 percent respectively.

4. Neither the percent acid insoluble or the percent dolomite in the carbonate fraction are reliable indicators for detecting reactive carbonate rocks. Each of these properties appear to have some effect upon the reactivity of the rock, but this effect appears to be so confounded with that of other factors as to render both unreliable indicators of reactivity.

5. There is a fairly good correlation between the two and eight week, and the four and eight week rock prism expansions, with the better correlation being obtained between the four and eight week results. Although this indicates that the length of rock prism test could be reduced below eight weeks, a decrease in length of the test period results in an increase in the number of delayed expansive rocks which will go undetected.

6. Some rocks classified as nonreactive in the eight-week prism test exhibited delayed expansion. All

of these rocks would be classified as the minor-expansive type, and their nondetection may or may not be serious.

Although the results clearly indicate the existence or reactive carbonate rocks in Missouri, it would be erroneous to assume that all of these reactive rocks were used in concretes. In making these tests, all rocks submitted to the laboratory for approval for use in concrete were tested. Approval for use in concrete was not withheld because of reactivity, but in many instances it was withheld because of failure to pass other acceptance tests. In addition, approval for use does not mean that a rock is actually used in concrete construction, as the contractor may purchase the rock elsewhere or the producer may furnish rock from other approved ledges in the same quarry. Furthermore, the records indicate that even if an approved reactive rock was used, there is an extremely high probability that it would be blended with nonreactive rock.

That some reactive rock is being used is clearly evident by the observed increase in pattern cracking in some of the newer concrete pavements. Although this increased cracking suggests that ultimately an undesirable amount of concrete deterioration may develop, there is presently no proof that this cracking will seriously decrease the service life of the effected pavements. Consequently, control of the

use of reactive rock does not appear to be warranted at this time. If, however, control of the use of reactive rock is ultimately deemed necessary, the results herein reported should be of great value.

INTRODUCTION

Until the late 1930's most concrete technologists believed that concrete aggregates were either entirely or practically chemically inert. It was then discovered that some siliceous aggregates were sufficiently reactive to the alkali in the cement to cause serious concrete deterioration. Later, within the past decade, it has been established that some carbonate aggregates are also reactive to the alkali in the cement.

As a result of these discoveries, the Missouri State Highway Department conducted studies to determine the reactivity of siliceous and carbonate aggregates used in Missouri. The initial studies on the siliceous aggregates were made in the 1940's, and the results indicated no serious alkali-silica reactions. However, there would appear to be a possibility that even a slight amount of cracking from an alkali-aggregate reaction might tend to decrease the frost resistance of some concretes.

As previously stated the alkali-carbonate reaction was not recognized until the late 1950's, but prior to its recognition, one Missouri carbonate rock had not been approved for use because laboratory concrete containing this rock had exhibited excessive early expansion. Later tests showed this carbonate rock to be highly reactive to alkali.

The recognition of the alkali-carbonate reaction caused concern in Missouri, because it was believed that (1) the excessive early expansion of the concrete, containing the previously mentioned carbonate rock, was due to alkali-carbonate reaction, and (2) an increased amount of the newer PCC pavements was exhibiting a pattern cracking typical of alkali-aggregate reaction. This concern led to initiation of a study* designed to determine the location, description, and degree of reactivity of the reactive carbonate rocks being used in concrete.

The reactivity of the carbonate rocks to alklai was determined from the expansion of small rock prisms stored in a one normal solution of sodium hydroxide. The results of the prism tests indicated that some rocks were reactive to alkali, with the degree of reactivity varying from slight to appreciable. These results also indicated considerable variation in the reactivity of the rock within a single ledge, and showed that many reactive rocks could meet all currently used acceptance tests.

As this study is now being concluded, the results of the rock prism test on samples from 1152 ledges representing 38 geological formations are presented in this final report.

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* See paper, "Alkali-Carbonate Reactivity - An Academic or a Practical Problem," by E. O. Axon and Junior Lind, Highway Research Record No. 45, 114-125 (1964).

In making these tests, all rocks submitted to the laboratory for approval for use in concrete were tested. This means that many rocks were tested which were not approved by the laboratory for use in concrete. However, the nonapproval by the laboratory was due to reasons other than the reactivity of the rock. In addition, approval for use does not mean that a rock is actually used in concrete construction, as the contractor may purchase the rock elsewhere or the producer may furnish rock from other approved ledges in the same quarry. Furthermore, the records indicate that even if an approved reactive rock was used, there is an extremely high probability that it would be blended with nonreactive rock.

That some reactive rock is being used is clearly evident by the observed increase in pattern cracking in some of the newer concrete pavements. Although this increased cracking suggests that ultimately an undesirable amount of concrete deterioration may develop, there is presently no proof that this cracking will seriously decrease the service performance of the effected pavements. Consequently, control of the use of reactive rock does not appear to be warranted at this time. If, however, control of the use of reactive rock is ultimately deemed necessary, the results herein reported should be of great value.

LABORATORY TESTS

As the samples for the rock prism test were obtained from ledge samples submitted to the laboratory, one or more samples of rock were obtained from each ledge in numerous quarries. This procedure was not sufficiently adequate to establish the range in reactivity for the rock in each ledge, but it did pinpoint the formations which contain reactive rock.

Four small prisms (approximately 5/16 x 5/16 x 1.5 in.) were sawn from each sample of rock obtained. Two each of these prisms were sawn perpendicular and parallel to the bedding plane.

These prisms were slightly larger in cross section than those used by other investigators, but the increase in size tends to reduce breakage during preparation. The length comparator (Fig. 1)* employed permits the use of square ends on the prisms. This innovation not only reduces the time required to prepare the prisms, but it should also reduce errors in measurement due to the loss in material from the ends of a less blunt specimen.

The comparator, shown in Fig. 1, is a modification of the one shown in HRB Record No. 45, p. 120. The principal

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* All Figures and Tables are located at the back of this paper.

modifications consist of a change in the graduation of the dial from 0.001 to 0.0001 inches, mounting of the comparator at an angle, and the addition of a lift lever to the dial. These changes not only increased the accuracy of the measurements, but also permits the observer to place the specimen and read the dial more easily and faster.

The prisms were measured dry, immersed in distilled water until a constant length was obtained, and then each pair of prisms was placed in an airtight container with approximately 50cc of one normal sodium hydroxide (1N NaOH) solution. At approximately weekly intervals (for eight weeks) the prisms were removed from the containers, rinsed lightly by dipping in distilled water, surface dried, measured, and returned to the alkaline solution. Prior to January 1964 some measurements were continued beyond the 8-week period, but since that date all measurements were continued for a minimum of 9 months and a maximum of 24 months.

In addition to the prism test, the chemical composition of many rocks, was determined. For these samples the percent of dolomite in the carbonate fraction was calculated from the results of the chemical analysis.

Some of the stones exhibiting various degrees of reactivity were also tested in concrete bars and beams. These tests were designed to determine the effect of (a) variations in the alkali content of the cement, and (b)

exposure to calcium and sodium chloride solutions, upon the expansion of concretes made with reactive rock. In addition, information concerning the relationship between rock prism and concrete expansion was obtained. The results of the tests on concrete are presented in another report.*

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*"Effects of Reactive Carbonate Aggregates on the Durability of Laboratory Concrete Specimens." Missouri Cooperative Highway Research Program Report 67-5.

RESULTS OF TESTS

General:

The eight-week prism test was completed on 1408 samples from 38 geological formations, 295 sources, and 1152 ledges. All of the reactive rock (0.05 percent or greater expansion in 8 weeks on prisms perpendicular to the bedding plane) were from 20 geological formations within the Pennsylvanian, Mississippian, Devonian, Ordovician, and Cambrian systems.

The distribution of the prism expansions and contractions, for prisms perpendicular to the bedding plane, is shown in Table 1. The distribution is made by ledges, rather than samples, because this should give a better estimate of the percentage of reactive stone.

The difference between the number of samples and number of ledges is due to the fact that two or more samples were tested from each of 185 ledges. The expansions and contractions shown in Table 1 are the average for all tests on samples from one ledge. The variation in reactivity of samples from the same ledge will be discussed later.

In studying the data in Table 1 it is obvious that the number of ledges sampled per geological formation was highly variable. Actually the number of ledges sampled per formation tends to be related to the probability of usage of

rock from a particular formation. In Table 2 the geological formations are tabulated in order of number of ledges sampled. These data show that 547 or 47.5 percent of the 1152 ledges were from formations 32, 3, and 35, indicating that these are the three formations most extensively used in Missouri. However, this indication could be misleading in that many of the ledges were not approved for use in concrete. The data in Table 3 show that 897 ledges received tentative approval for use in concrete, and 255 ledges were not approved.

The data in Table 1 shows that the average eight-week rock prism expansion for 112 ledges exceeded 0.05 percent. The data in Table 3 show that of these 112 ledges 49 (43.8 percent) were tentatively approved for use in concrete and 63 (56.2 percent) were not approved.

The data in Table 1 also shows that the average eight-week rock prism expansion for 1040 ledges was less than 0.05 percent. The data in Table 3 show that of these 1040 ledges 848 (81.5 percent) were tentatively approved for use in concrete, and 192 (18.5 percent) were not approved. This indicates that the ledges containing reactive rock are more susceptible to rejection for use in concrete, but 49 (5.5 percent) of the 897 ledges tentatively approved contained rock exhibiting 0.05 or more percent expansion in the eight-week rock prism test. Furthermore, the data in Table 3 indicate that the rocks exhibiting 0.20 or more percent expansion

had a greater probability of being approved for use in concrete than the rocks exhibiting expansions from 0.05 to 0.199 percent.

These results show that of the rock prisms representing the 1152 ledges, 112 (9.7 percent), 68 (5.9 percent), 38 (3.3 percent), 27 (2.3 percent), and 21 (1.8 percent) showed expansions in the eight-week prism test of or in excess of 0.05, 0.10, 0.20, 0.30, and 0.50 percent respectively. Of the rock prisms representing the 897 ledges tentatively approved for use in concrete, 49 (5.5 percent), 32 (3.6 percent), 20 (2.2 percent), 14 (1.6 percent), and 11 (1.2 percent) showed expansions in the eight-week prism test of or in excess of 0.05, 0.10, 0.20, 0.30, and 0.50 percent respectively.

These percentages are not large, but they are average values for all ledges. The results in Tables 2 and 4 clearly show that the percentage of reactive stone in some formations is appreciably higher than this state wide average. The results in these two tables also show that for some formations (32, 26, 4, 13, and 15) the percentage of reactive stone is about the same in both the approved and non-approved ledges. In other formations (35, 5, 34, 27, 24, 8, 31, 11, and 16) the reactive stone was largely or completely in the non-approved ledges. The reason why the standard acceptance tests tended to reject reactive stone in some formations and

not in others is unknown. Obviously, however, the data in Table 4 show that only 6 formations contained approved stone exhibiting more than 0.20 percent expansion in the eight-week rock prism test.

Variation in Reactivity within a Ledge:

The preceding discussion has been based upon the average results of the eight-week rock prism test. For 967 ledges this average was obtained with one sample, whereas for 185 ledges the average was that obtained on two or more samples. The results of the prism test on samples from these 185 ledges are shown in Table 5. In this table the ledges have been divided into three groups, as follows:

Group 1, consisting of 136 ledges, contains those stones where the maximum prism expansion on individual samples was less than 0.05 percent.

Group 2, consisting of 11 ledges, contains those stones where the maximum prism expansion on individual samples was greater than or equal to 0.05 percent, but the average prism expansion for all samples from a ledge was less than 0.05 percent.

Group 3, consisting of 38 ledges, contains those stones where the average prism expansion for all samples from a ledge was greater than or equal to 0.05 percent.

Obviously the stones in ledges within Groups 1 and 2 have been previously considered as nonreactive; whereas the stones in ledges within Group 3 have been previously considered as reactive. However, it should be evident that the stone in 23 of the 49 ledges in Groups 2 and 3 had individual samples exhibiting both contraction and expansion of 0.05 percent or greater. Consequently, it is impossible to predict how the reactivity of the stone in each of these 23 ledges would have been classified if only one sample per ledge had been tested. The stone in one (not approved) of these 23 ledges is most unusual in that prism expansions on different samples ranged from contraction to approximately 7.0 percent expansion. Consequently, these results indicate that the reactivity of the stone within one ledge can be variable and in some instances highly variable. This would appear to present problems in establishing control of the use of reactive stone, if such control becomes necessary.

There is, of course, the possibility that the variation in results, for companion samples of stone from the same ledge, could be due to variations in the test procedure alone. However, this is deemed most unlikely because the chemical analysis of the reactive stones, and at times visible observations, indicated appreciable variation in the composition of stones from the same ledge. Consequently, there

appears to be no reason to doubt that the stone within some ledges can and does vary appreciably in reactivity. This presents a serious problem in determining the reactivity of the stone within a ledge, especially if control of the use of reactive stone becomes necessary.

Chemical Analyses:

Chemical analyses were made on 219 of the 1408 samples, 24 of the 38 geological formations and 169 of the 1152 ledges. Two or more chemical analyses were made on samples from each of 29 ledges. Initially chemical tests were made on all samples, then they were made on reactive stones only, and finally all chemical analyses were stopped. Consequently, there is some bias in the results of the chemical tests in that a higher percentage of the reactive stones were tested.

The results of the chemical analyses have been studied and no consistent relationship between stone composition and reactivity to alkali or standard acceptance tests could be established. Consequently, it does not appear necessary to include all of the results of the chemical analyses in this report. However, other investigators have indicated the existance of a relationship between percent acid insoluble and percent dolomite in the carbonate fraction and the reactivity to alkali. It is, therefore, deemed

desirable to present and discuss the data obtained concerning these two relationships.

The data concerning the relationship between percent acid insoluble and 8 week rock prism expansions are presented in Tables 6 and 7. These data clearly show that the relationship between percent acid insoluble and rock prism expansions is not clearcut. Some reactive stone occurred in all four ranges of percend acid insoluble, although the percent of samples exhibiting reactivity greatly increased when the percent acid insoluble was 5.0 percent or greater.

The best relationship in Table 7 is that between percent acid insoluble and present acceptance tests. The percentage of stones approved for use in concrete very definitely had a tendency to vary indirectly with the percent acid insoluble. But it should be observed that the reactive stones were approved in about the same ratio as the entire group, indicating that present acceptance tests do not detect the properties of a stone which make it reactive to alkali.

Despite the relationship between percent acid insoluble and present acceptance tests, it is very apparent that the relationship is not so clearcut that approval of stone could be based upon the percent of acid insoluble. There is a trend, but as previously stated no consistent

relationship could be established between the chemical composition of a stone and either reactivity to alkali or standard acceptance tests.

The data concerning the relationship between the percent dolomite in the carbonate fraction and the 8 week rock prism expansions are presented in Tables 8 and 9. Again this relationship is not clearcut as some reactive stones were found in all five ranges of percent dolomite. There is a trend indicating that a higher percentage of the stones are reactive when the percent dolomite in the carbonate fraction ranges from 20 to 80. The percent (76.5) of reactive stone in the 40 to 60 range is slightly less than that (83.3) in the 60 to 80 range, and slightly greater than that (73.0) in the 20 to 40 range. Actually this difference in the percent of reactive stone in these three ranges in dolomite content is not considered significant, as the percentage of reactive stone varies indirectly with the number of samples.

The percent dolomite in the carbonate fraction does not appear to be related to present acceptance tests. The percent of samples approved in the first four groups did not vary appreciably. However, it appears that present acceptance tests tend to reject samples of highest dolomite content.

These results definitely indicate that neither the percent acid insoluble or the percent dolomite in the

carbonate fraction are reliable indicators for detecting reactive carbonate rocks. Each of these properties appears to have some effect upon the reactivity of the rock, but this effect appears to be so confounded with that of other factors as to render both unreliable indicators of reactivity.

Length of Prism Test:

In conducting the rock prism test various investigators have presented results obtained after from two to eight weeks. This variability in length of test period creates difficulties in comparing test results. It also raises the question as to whether test periods of two or four weeks are as adequate as eight weeks. Confounding this question of length of test period is the fact that some rocks exhibit a delayed reaction. This delayed reaction may not occur until the prisms have been in alkali for a considerable period in excess of eight weeks.

As a vast amount of data has been collected in this investigation, it appears desirable to evaluate the effect of the length of the test period. To understand the possible effect of variation in length of test period, typical expansion curves are presented in Figure 2. These curves represent the average expansions for 94 of 128 samples exhibiting expansions of from 0.05 to 0.799 percent at eight weeks. Each curve in Figure 2 represents the average expansions for

all samples exhibiting eight week expansions within the ranges shown on the curve. Obviously the expansions are not linear with age, but the shape of all curves are similar and this indicates the possibility of using a test period of less than eight weeks.

Of the 1408 samples tested there were 155 which exhibited eight week expansion of 0.05 percent or greater. Of these 155 samples, 48 exhibited expansion of 0.20 percent or greater at 2 weeks. In Figure 3 the relationships between the eight and two week expansions for the 155 and 48 samples are shown, together with the plotted points for the 48 samples. Obviously the relationship is approximately the same for both groups of samples. The regression equation for the 155 samples is $y = 1.7295x + 0.0608$, and the coefficient of correlation is 0.9578. The formula for the regression equation for the 48 samples is $y = 1.6781x + 0.1628$, and the coefficient of correlation is 0.9422. This indicates that there is a fairly good relationship between the 2 and 8 week expansions.

In Fig. 4 a similar comparison is made between the 4 and 8 week expansions. However, it will be noted that 61 of the 155 samples exhibited expansion of 0.20 or greater percent at 4 weeks. The regression equation for the 155 samples is $y = 1.2544x + 0.0172$, and the coefficient of correlation is 0.992. Obviously the regression equation and

coefficient of correlation is approximately the same for the 61 samples. This indicates that a better relationship exists between the 4 and 8 week expansions than between the two and eight week expansions.

These data would indicate that the length of the prism test could be reduced to 2 or 4 weeks, but this indication could be misleading. For example, the y intercepts in the preceding three equations are 0.0608, 0.1628, and 0.0172. This means that when y is less than these values x is negative or contraction. Consequently, for the second equation all values of y less than 0.1628 would result in negative values for x. In checking the data it was found that 2 of 155 samples did show contraction at both 2 and 4 weeks even though these same samples showed more than 0.05 percent expansion at 8 weeks. In addition 4 of 155 samples showed zero percent expansion at two weeks and from 0.06 to 0.19 percent expansion at eight weeks. This is an indication of slightly delayed expansion, and points up the fact that decreasing the length of the test period will result in an increase in the number of reactive stones undetected.

As previously stated only a portion of the prism tests was continued beyond eight weeks. But of 887 samples continued beyond (12 months or more) eight weeks only eight samples, see Table 10, exhibiting expansions at eight weeks of less than 0.05 percent showed expansions at twelve months

equal to or in excess of 0.10 percent. At twelve months these eight samples exhibited expansions ranging from 0.10 to 0.18 percent. Consequently, these rocks would be classified as of the minor-expansive type. In addition, other samples exhibited a lesser amount of delayed expansion, but the present state of knowledge does not permit an evaluation of need for control of these minor-expansive rocks.

The point is that some reactive rocks can be detected by rock prism tests of either two, four, or eight weeks, whereas other reactive rocks cannot be detected even by the longer test period. But the number of undetected reactive rocks varies inversely with the length of the test period. The results reported herein tend to indicate that the most reactive rocks would be detected by a two week rock prism test, but these results provide little if any information concerning the desirable length of the rock prism test. The desirable length of the test period cannot be established until the acceptable amount of reactivity is established. Factors affecting the acceptable amount of reactivity were discussed in the companion report previously referred to on page 10 and will not be further discussed here.

Table 1

DISTRIBUTION OF AVERAGE PRISM EXPANSIONS AND CONTRACTIONS - 8 WEEK TEST PERIOD

Formation Number	Total Number Ledges	Number of Ledges Exhibiting Expansion (Percent)							
		<0	0	0.001 thru 0.049	0.050 thru 0.099	0.100 thru 0.199	0.200 thru 0.299	0.300 thru 0.499	≥0.500
1	2	2	-	-	-	-	-	-	-
2	21	19	2	-	-	-	-	-	-
3	181	120	23	35	2	-	-	-	-
4	44	18	4	15	2	3	1	-	1
5	37	10	-	16	3	2	-	1	6
6	1	-	-	1	-	-	-	-	-
7	26	20	3	3	-	-	-	-	-
8	13	4	3	5	-	1	-	-	-
9	45	28	1	12	1	1	2	-	-
10	11	8	2	1	-	-	-	-	-
11	3	-	-	-	2	1	-	-	-
12	9	5	1	2	1	-	-	-	-
13	47	25	7	12	-	1	1	1	-
14	3	2	-	1	-	-	-	-	-
15	4	-	1	2	-	-	-	-	1
16	3	1	-	1	1	-	-	-	-
17	19	3	4	11	-	1	-	-	-
18	3	2	1	-	-	-	-	-	-
19	3	1	1	1	-	-	-	-	-
20	12	7	-	5	-	-	-	-	-
21	11	5	1	5	-	-	-	-	-
22	40	29	4	6	1	-	-	-	-
23	13	5	4	4	-	-	-	-	-
24	14	8	-	3	1	2	-	-	-
25	14	9	1	4	-	-	-	-	-
26	90	40	16	24	5	1	2	1	1
27	17	5	3	4	2	3	-	-	-
28	7	6	1	-	-	-	-	-	-
29	1	-	-	1	-	-	-	-	-
30	3	2	-	1	-	-	-	-	-
31	13	4	-	3	2	3	-	-	1
32	188	118	10	28	16	5	2	2	7
33	36	12	2	13	3	2	1	-	3
34	21	12	2	3	1	1	1	1	-
35	178	102	31	39	1	3	1	-	1
36	1	1	-	-	-	-	-	-	-
37	13	11	1	1	-	-	-	-	-
38	5	5	-	-	-	-	-	-	-
Totals	1152	649	129	262	44	30	11	6	21
Percent	100	56.3	11.2	22.7	3.8	2.6	1.0	0.5	1.8

Table 2

TABULATION INDICATING THE PROBABLE RELATIVE OCCURRENCE OF REACTIVE ROCK FROM EACH GEOLOGICAL FORMATION

Formation Number	Total Number Ledges	Percent of all Ledges Sampled	Cumulative Percent of Ledges Sampled	Percent of Ledges Showing Expansions ≥ (Percent)				
				0.05	0.10	0.20	0.30	0.50
32	188	16.3	16.3	17.0	8.5	5.9	4.8	3.7
3	181	15.7	32.0	1.1	0	0	0	0
35	178	15.5	47.5	3.4	2.8	1.1	0.6	0.6
26	90	7.8	55.3	11.1	5.6	4.4	2.2	1.1
13	47	4.1	59.4	6.4	6.4	4.3	2.1	0
9	45	3.9	63.3	8.9	6.7	4.4	0	0
4	44	3.8	67.1	15.9	11.4	4.5	2.3	2.3
22	40	3.5	70.6	2.5	0	0	0	0
5	37	3.2	73.8	32.4	24.4	18.9	18.9	16.2
33	36	3.1	76.9	25.0	16.7	11.1	8.3	8.3
7	26	2.3	79.2	0	0	0	0	0
2	21	1.8	81.0	0	0	0	0	0
34	21	1.8	82.8	19.0	14.3	9.5	4.8	0
17	19	1.6	84.4	5.3	5.3	0	0	0
27	17	1.5	85.9	29.4	17.6	0	0	0
24	14	1.2	87.1	21.4	14.3	0	0	0
25	14	1.2	88.3	0	0	0	0	0
8	13	1.1	89.4	7.7	7.7	0	0	0
23	13	1.1	90.5	0	0	0	0	0
31	13	1.1	91.6	46.1	30.8	7.7	7.7	7.7
37	13	1.1	92.7	0	0	0	0	0
20	12	1.0	93.7	0	0	0	0	0
10	11	1.0	94.7	0	0	0	0	0
21	11	1.0	95.7	0	0	0	0	0
12	9	0.8	96.5	11.1	0	0	0	0
28	7	0.6	97.1	0	0	0	0	0
38	5	0.4	97.5	0	0	0	0	0
15	4	0.3	97.8	25.0	25.0	25.0	25.0	25.0
11	3	0.3	98.1	100.0	33.3	0	0	0
14	3	0.3	98.4	0	0	0	0	0
16	3	0.3	98.7	33.3	0	0	0	0
18	3	0.3	99.0	0	0	0	0	0
19	3	0.3	99.3	0	0	0	0	0
30	3	0.3	99.6	0	0	0	0	0
1	2	0.1	99.7	0	0	0	0	0
6	1	0.1	99.8	0	0	0	0	0
29	1	0.1	99.9	0	0	0	0	0
36	1	0.1	100.0	0	0	0	0	0

Table 3

RELATIONSHIP BETWEEN ROCK PRISM EXPANSIONS AND TENTATIVE APPROVAL FOR USE IN CONCRETE

Formation Number	Number of Ledges Tentatively Approved for Use in Concrete when the Average Rock Prism Expansions were											
	<0.05		0.050 thru 0.099		0.100 thru 0.199		0.200 thru 0.299		0.300 thru 0.499		≥0.500	
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
32	137	19	6	10	4	1	2	0	1	1	6	1
3	159	20	1	1	0	0	0	0	0	0	0	0
35	148	24	1	0	0	3	0	1	0	0	0	1
26	76	4	4	1	1	0	2	0	1	0	1	0
13	36	8	0	0	1	0	0	1	1	0	0	0
9	20	21	0	1	1	0	0	2	0	0	0	0
4	36	1	1	1	3	0	1	0	0	0	1	0
22	29	10	1	0	0	0	0	0	0	0	0	0
5	2	23	1	2	0	2	0	0	0	1	0	6
33	20	7	1	2	1	1	1	0	0	0	1	2
7	21	5	0	0	0	0	0	0	0	0	0	0
2	18	3	0	0	0	0	0	0	0	0	0	0
34	13	4	1	0	0	1	0	1	0	1	0	0
17	17	1	0	0	1	0	0	0	0	0	0	0
27	7	5	0	2	0	3	0	0	0	0	0	0
24	8	3	0	1	0	2	0	0	0	0	0	0
25	13	1	0	0	0	0	0	0	0	0	0	0
8	3	9	0	0	0	1	0	0	0	0	0	0
23	11	2	0	0	0	0	0	0	0	0	0	0
31	6	1	0	2	0	3	0	0	0	0	1	0
37	13	0	0	0	0	0	0	0	0	0	0	0
20	0	12	0	0	0	0	0	0	0	0	0	0
10	10	1	0	0	0	0	0	0	0	0	0	0
21	11	0	0	0	0	0	0	0	0	0	0	0
12	8	0	0	1	0	0	0	0	0	0	0	0
28	7	0	0	0	0	0	0	0	0	0	0	0
38	4	1	0	0	0	0	0	0	0	0	0	0
15	3	0	0	0	0	0	0	0	0	0	1	0
11	0	0	0	2	0	1	0	0	0	0	0	0
14	2	1	0	0	0	0	0	0	0	0	0	0
16	0	2	0	1	0	0	0	0	0	0	0	0
18	1	2	0	0	0	0	0	0	0	0	0	0
19	3	0	0	0	0	0	0	0	0	0	0	0
30	3	0	0	0	0	0	0	0	0	0	0	0
1	2	0	0	0	0	0	0	0	0	0	0	0
6	1	0	0	0	0	0	0	0	0	0	0	0
29	0	1	0	0	0	0	0	0	0	0	0	0
36	0	1	0	0	0	0	0	0	0	0	0	0
Totals	848	192	17	27	12	18	6	5	3	3	11	10

Table 4

TABULATION INDICATING THE PROBABLE RELATIVE USAGE OF REACTIVE ROCK FROM EACH GEOLOGICAL FORMATION

Formation Number	Total Number Ledges Approved	Percent of all Ledges Approved	Cumulative Percent of Ledges Approved	Percent of Ledges Showing Expansions ≥ (Percent)				
				0.05	0.10	0.20	0.30	0.50
32	156	17.4	17.4	12.2	8.3	5.8	5.1	3.8
3	160	17.8	35.2	0.6	0	0	0	0
35	149	16.6	51.8	0.7	0	0	0	0
26	85	9.5	61.3	10.6	5.9	4.7	2.4	1.2
13	38	4.2	65.5	5.3	5.3	2.6	2.6	0
9	21	2.4	67.9	4.8	4.8	0	0	0
4	42	4.7	72.6	14.3	11.9	4.8	2.4	2.4
22	30	3.3	75.9	3.3	0	0	0	0
5	3	0.3	76.2	33.3	0	0	0	0
33	24	2.7	78.9	16.7	12.5	8.3	4.2	4.2
7	21	2.3	81.2	0	0	0	0	0
2	18	2.0	83.2	0	0	0	0	0
34	14	1.6	84.8	7.1	0	0	0	0
17	18	2.0	86.8	5.6	5.6	0	0	0
27	7	0.8	87.6	0	0	0	0	0
24	8	0.9	88.5	0	0	0	0	0
25	13	1.5	90.0	0	0	0	0	0
8	3	0.3	90.3	0	0	0	0	0
23	11	1.2	91.5	0	0	0	0	0
31	7	0.8	92.3	0	0	0	0	0
37	13	1.5	93.8	0	0	0	0	0
20	0	0	93.8	0	0	0	0	0
10	10	1.1	94.9	0	0	0	0	0
21	11	1.2	96.1	0	0	0	0	0
12	8	0.9	97.0	0	0	0	0	0
28	7	0.8	97.8	0	0	0	0	0
38	4	0.5	98.3	0	0	0	0	0
15	4	0.5	98.8	25.0	25.0	25.0	25.0	25.0
11	0	0	98.8	0	0	0	0	0
14	2	0.2	99.0	0	0	0	0	0
16	0	0	99.0	0	0	0	0	0
18	1	0.1	99.1	0	0	0	0	0
19	3	0.3	99.4	0	0	0	0	0
30	3	0.3	99.7	0	0	0	0	0
1	2	0.2	99.9	0	0	0	0	0
6	1	0.1	100.0	0	0	0	0	0
29	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0

Table 5

RANGE IN EIGHT WEEK ROCK PRISM EXPANSIONS AND CONTRACTIONS OBTAINED WITH MULTIPLE SAMPLES FROM 185 LEDGES

Group and Number of Ledges	Expansions and Contractions of Individual Samples Per Ledge								Average Expansion and Contraction Per Ledge			
	Minimum				Maximum							
	<0	0	0.001 thru 0.049	≥0.05	<0	0	0.001 thru 0.049	≥0.05	<0	0	0.001 thru 0.049	≥0.05
	-	12	-	-	-	6	6	-	-	6	6	-
Group 1 136	-	-	10	-	-	-	10	-	-	-	10	-
	114	-	-	-	60	23	31	-	100	1	13	-
	-	-	-	-	-	-	-	-	-	-	-	-
Group 2 11	-	3	-	-	-	-	-	3	-	-	3	-
	8	-	-	-	-	-	-	8	-	-	8	-
	-	3	-	-	-	-	-	3	-	-	-	3
Group 3 38	-	-	9	11	-	-	-	20	-	-	-	20
	15	-	-	-	-	-	-	15	-	-	-	15
Totals 185	137	18	19	11	60	29	47	49	100	7	40	38

Table 6

PERCENT ACID INSOLUBLE VS.
8 WEEK ROCK PRISM EXPANSIONS

Percent Acid Insoluble	Number of Samples		Number of Samples Exhibiting Prism Expansions at 8 Weeks of (Percent)						
			<0	0.001 thru 0.049	0.050 thru 0.099	0.100 thru 0.199	0.200 thru 0.299	0.300 thru 0.499	0.500 or greater
0 to 4.99	Total	125	79	23	8	6	1	3	5
	Approved	102	66	18	6	6	1	3	2
	Nonapproved	23	13	5	2	0	0	0	3
5.0 to 9.99	Total	59	15	11	7	9	2	2	13
	Approved	31	3	7	3	5	1	2	10
	Nonapproved	28	12	4	4	4	1	0	3
10.0 to 19.99	Total	28	9	4	2	4	2	2	5
	Approved	6	2	0	1	0	0	1	2
	Nonapproved	22	7	4	1	4	2	1	3
20.0 or Greater	Total	7	2	1	3	0	1	0	0
	Approved	1	1	0	0	0	0	0	0
	Nonapproved	6	1	1	3	0	1	0	0
Grand Totals									
	Total	219	105	39	20	19	6	7	23
	Approved	140	72	25	10	11	2	6	14
	Nonapproved	79	33	14	10	8	4	1	9

Table 7

SUMMARY TABULATION OF PERCENT ACID INSOLUBLE VS. REACTIVITY OF STONE TO ALKALI

Percent Acid Insoluble	Samples		Samples Reactive(1)		
	Number	% Approved	Number	Percent(2)	% Approved(3)
0 to 4.99	125	81.6	23	18.4	78.3
5.0 to 9.99	59	52.5	33	55.9	63.6
10.0 to 19.99	28	21.4	15	53.6	26.7
≥ 20.0	7	14.3	4	52.1	0.0
0 to ≥ 20.0	219	63.9	75	34.2	57.3

(1) Prism expansions of 0.05 percent or greater in eight weeks.
(2) Percent of total number of samples in group.
(3) Percent of reactive samples approved.

Table 8

PERCENT DOLOMITE IN CARBONATE FRACTION VS.
8 WEEK ROCK PRISM EXPANSIONS

Percent Dolomite(1)	Number of Samples		Percent Prism Expansion (8 weeks) ≤0	0.001 thru 0.049	0.050 thru 0.099	0.100 thru 0.199	0.200 thru 0.299	0.300 thru 0.499	0.500 or greater
0	Total	128	80	21	7	11	3	3	3
to	Approved	92	62	13	5	6	1	2	3
19.99	Nonapproved	36	18	8	2	5	2	1	0
20.0	Total	37	4	6	6	4	3	2	12
to	Approved	23	3	6	3	3	1	2	5
39.99	Nonapproved	14	1	0	3	1	2	0	7
40.0	Total	17	2	2	3	2	0	2	6
to	Approved	13	2	2	2	1	0	2	4
59.99	Nonapproved	4	0	0	1	1	0	0	2
60.0	Total	6	0	1	1	2	0	0	2
to	Approved	4	0	1	0	1	0	0	2
79.99	Nonapproved	2	0	0	1	1	0	0	0
80.0	Total	31	19	9	3	0	0	0	0
to	Approved	8	5	3	0	0	0	0	0
100.0	Nonapproved	23	14	6	3	0	0	0	0
	Grand Totals								
	Total	219	105	39	20	19	6	7	23
	Approved	140	72	25	10	11	2	6	14
	Nonapproved	79	33	14	10	8	4	1	9

(1) In carbonate fraction.

Table 9

SUMMARY TABULATION OF PERCENT DOLOMITE IN CARBONATE FRACTION VS. REACTIVITY OF STONE TO ALKALI

Percent Dolomite(1)	Samples		Samples Reactive(2)		
	Number	% Approved	Number	Percent(3)	% Approved(4)
0 to 19.99	128	71.9	27	21.1	63.0
20 to 39.99	37	62.2	27	73.0	51.9
40 to 59.99	17	76.5	13	76.5	69.2
60 to 79.99	6	66.7	5	83.3	60.0
80 to 100.0	31	25.8	3	9.7	0.0
0 to 100.0	219	63.9	75	34.2	57.3

(1) In carbonate fraction.
(2) Prism expansion of 0.05 percent or greater at eight weeks.
(3) Percent of total number of samples in the group.
(4) Percent of reactive samples approved.

Table 10

Expansions of Rock Prisms Having a Delayed Reaction (Must have more than 0.100 percent expansion at 12 months and less than 0.050 percent at 8 weeks)

Source	Age in Weeks 1	2	3	4	5	6	7	8
K-101	0	0	-.007	-.004	-.004	-.010	+.017	+.024
B-300	+.013	+.013	+.013	+.013	+.013	+.013	+.013	+.013
P-100	+.017	+.035	+.035	+.035	+.035	+.035	+.025	+.035
T-200	+.013	+.007	0	0	-.008	-.008	-.018	-.018
B-102	-.004	-.010	-.010	-.010	-.010	-.010	-.010	-.007
B-102	+.004	+.004	+.010	+.007	+.007	+.013	+.010	+.010
OS-13	+.014	+.025	+.020	+.020	+.024	+.020	+.015	+.010
OS-13	+.013	+.013	+.013	+.010	+.013	+.013	+.013	+.013

	Age in Months 3	6	9	12	15	18	21	24
K-101	+.068	+.096	+.099	+.103	+.113	+.103	-	-
B-300	+.013	+.069	+.096	+.113	+.142	+.158	-	-
P-100	+.050	+.118	+.156	+.181	+.202	+.243	+.313	+.313
T-200	-.018	+.027	+.100	+.137	+.178	+.231	+.310	+.344
B-102	-.007	+.011	+.075	+.095	+.144	+.172	+.207	+.216
B-102	+.010	+.047	+.115	+.126	+.151	+.165	+.172	+.169
OS-13	+.021	+.050	+.090	+.117	+.151	+.166	-	+.188
OS-13	+.024	+.040	+.080	+.103	+.139	+.147	+.183	+.207

Fig. 1 — Comparator for measuring small rock prisms.

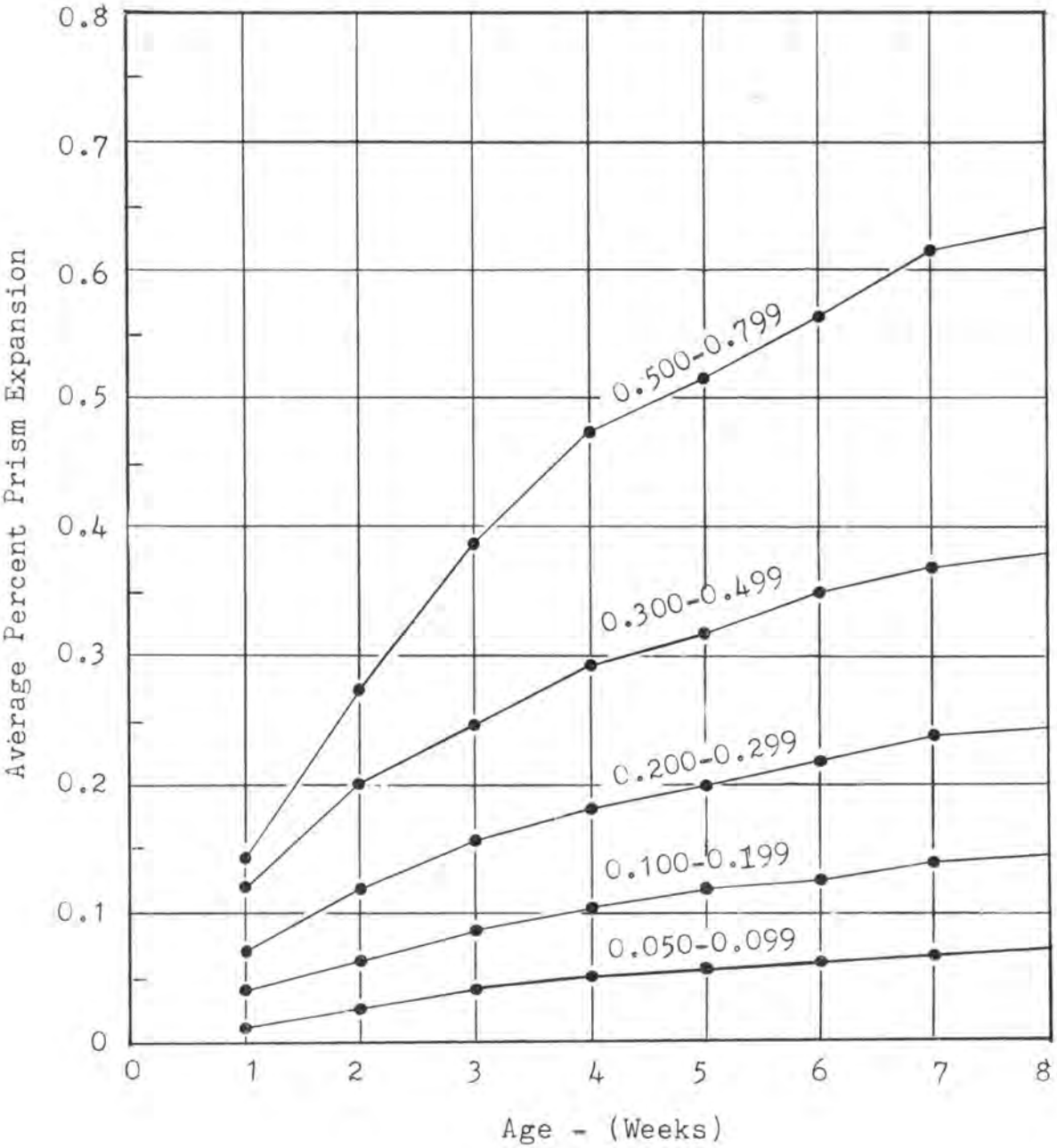

Fig. 2 - Typical Expansion Curves for Samples Exhibiting From 0.05 to 0.799 Percent Expansions at 8 Weeks

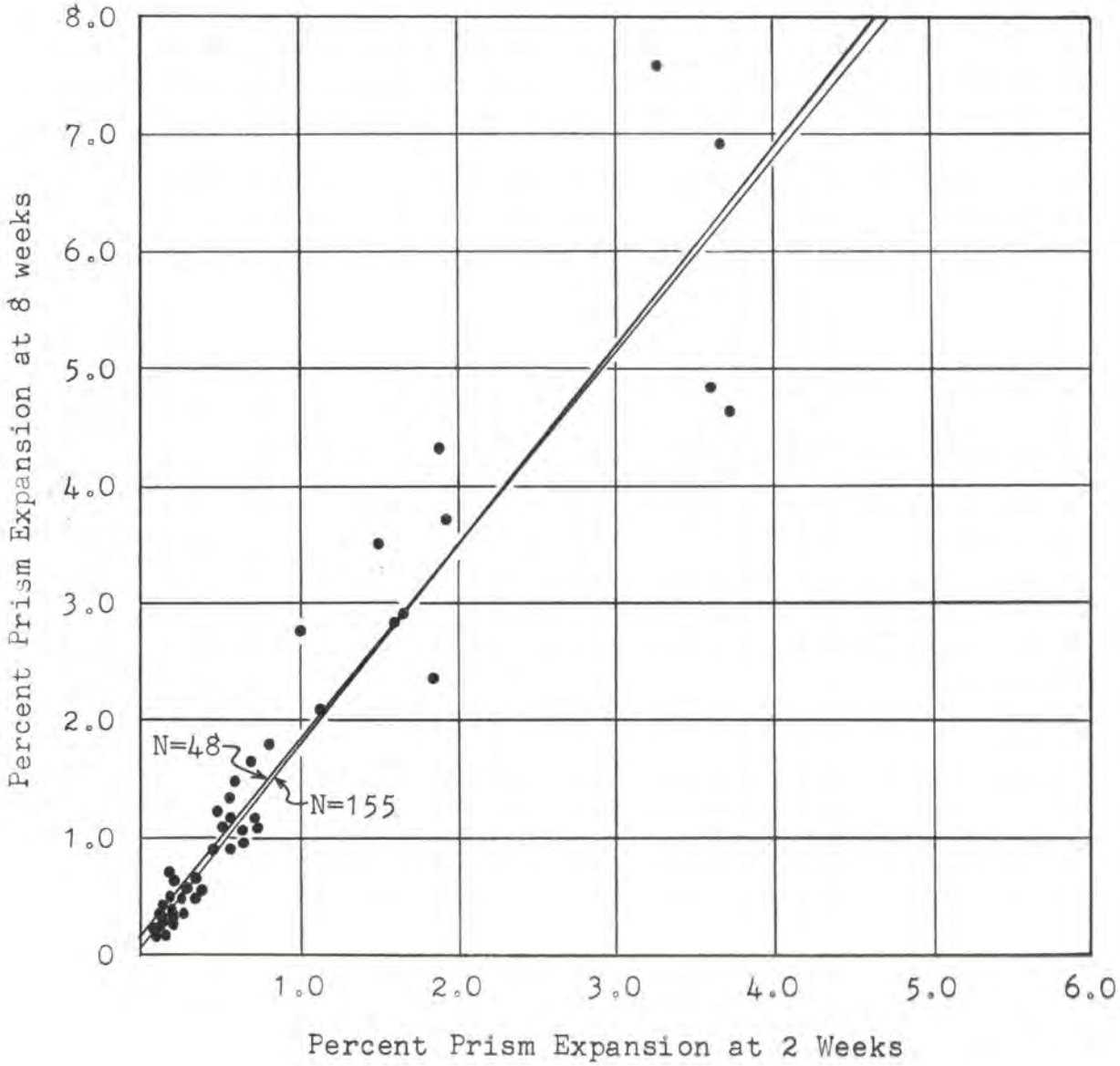

Fig. 3 - Comparison of 2 Vs. 8 Week Rock Prism Expansions

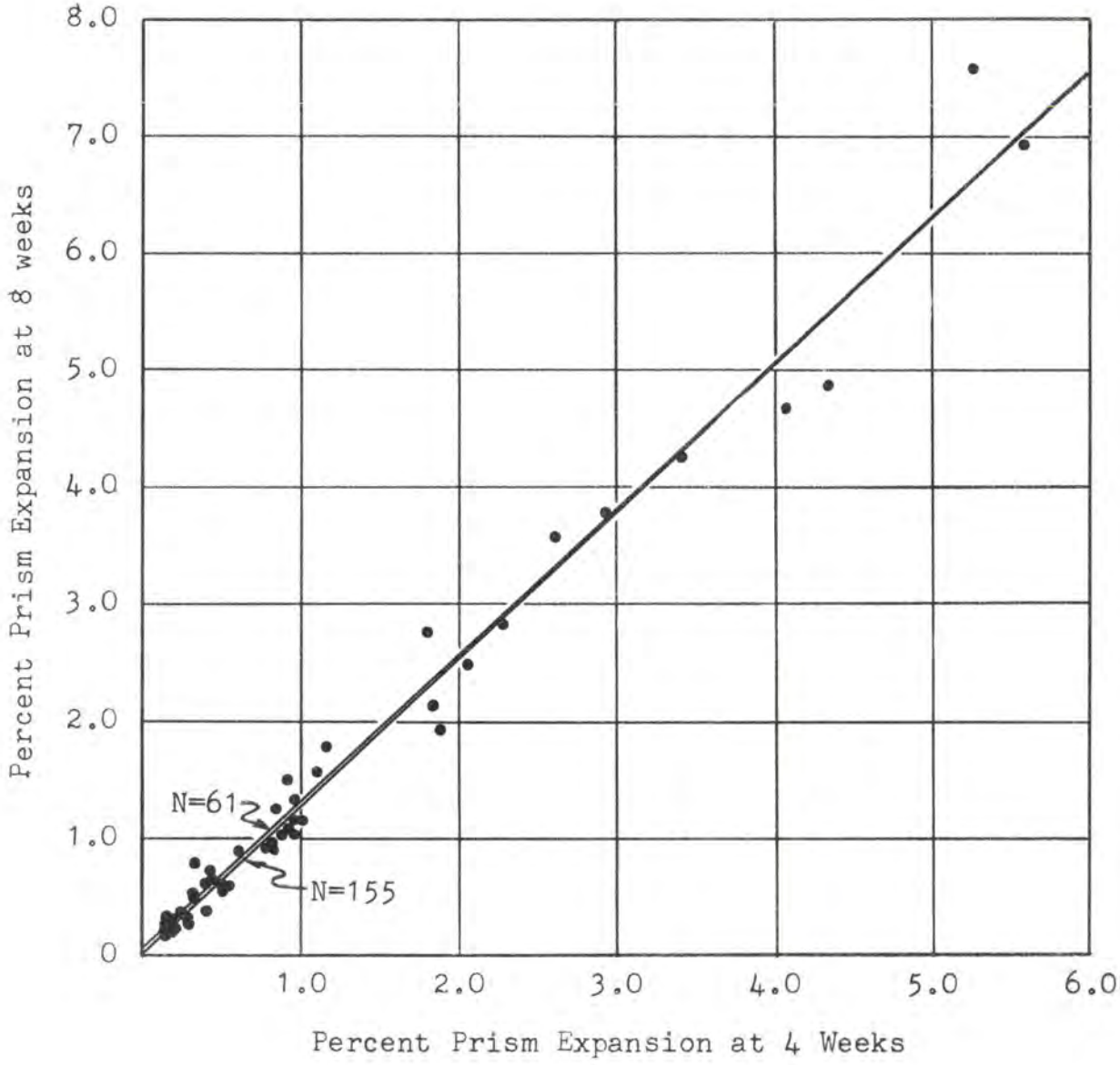

Fig. 4 - Comparison of 4 Vs. 8 Week Rock Prism Expansions

MoDOT Library
RD0016018