MISCELLANEOUS PAPER C-69-15

POTENTIAL ALKALI REACTIVITY OF CARBONATE ROCK FROM SIX QUARRIES

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FOREWORD

This report presents the results of a laboratory investigation authorized by a letter dated 20 June 1963 from the Office, Chief of Engineers (ENGCW-EC), to the Division Engineer, U. S. Army Engineer Division, Ohio River, subject, "Aggregate from North Fork of Pound Reservoir Project."

The testing was initiated in the fall of 1963 and continued into 1968. The work was performed as Item ES 603.4 of the Engineering Studies Program of OCE in the Concrete Division of the U. S. Army Engineer Waterways Experiment Station (WES) by Mr. Wilbur I. Luke, Mr. Alan D. Buck, and other staff members under the direction of Mrs. Katharine Mather and Messrs. R. V. Tye, Bryant Mather, and T. B. Kennedy. The cooperation of Mr. Howard H. Newlon, Jr., of the Virginia Highway Research Council is acknowledged with appreciation.

Directors of WES during the conduct of this study and the preparation of this report were COL Alex G. Sutton, Jr., CE, COL John R. Oswalt, Jr., CE, and COL Levi A. Brown, CE. Technical Director was Mr. J. B. Tiffany.

CONTENTS

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters

SUMMARY

Forty-one samples of carbonate rock from six quarries in Virginia and Kentucky were tested for potential alkali-carbonate rock reactivity. This reaction may take place when certain carbonate rocks are used as aggregates in concrete. Since the expansion that accompanies this reaction may be deleterious to concrete, criteria have been established to detect potentially reactive rock. These criteria are described in Appendix A.

Petrographic, physical, and chemical data were developed for each sample. In most instances, the expansion data were obtained by periodic measurement of the length changes of pairs of small rock specimens, selected to represent each sample, that were stored in sodium hydroxide solution. Three of the 41 samples, however, were represented by 5 length-change specimens each. These data were examined and compared to determine if the criteria for identification of potentially reactive rocks appeared to be effective. In general, the validity of the criteria was confirmed. However, there were certain exceptions in which petrographic criteria failed to provide a basis for accurately predicting the results of expansion tests.

The failure of the currently used criteria to always identify reactive rocks suggests that (a) tests for determining potential reactivity of samples of rock that contain detectable amounts of dolomite and that have a matrix that is essentially limy mud should include length-change determinations, and (b) length-change determinations should be made on at least two specimens from each rock sample. It is indicated that these specimens should preferably be from adjacent locations rather than from one above the other.

Additional work should be done to refine and improve the criteria now used to classify potential reactivity. This additional work should include a study of the effects on concrete of the use of late-expanding rocks as aggregate.

Based on the length-change data, it is indicated that the material from one of these quarries would not be expected to participate in expansive alkali-carbonate rock reaction to any degree whatever. Material from the other five quarries is expected to contain greater or lesser amounts of rock that could participate in this reaction in varying degrees. Based on the criteria that have been proposed for application in such cases (Appendix A), and in the absence of service record data on the performance of aggregate from these sources, the quarries are rated as follows:

Quarry	
2	No indication of reactivity
3	Approximately 15% potentially reactive rock from one ledge near base of operating face

(Continued)

Quarry	
5	Approximately 24% potentially reactive rock from two lowest ledges; presumably readily avoided by quarrying only from above these ledges
1	Approximately 30% potentially reactive rock from three ledges distributed through the section; should not be listed as a source from which satisfactory material could be obtained without additional study
6	Over 50% potentially reactive*
4	Approximately 70% potentially reactive*

* Quarries 6 and 4 may be said to have service record data indicating excessive reactivity since previous investigators have shown samples from these sources to undergo excessive expansion. In this study, excessive expansion was noted on specimens from samples representing more than half the anticipated production, taken from ledges that could not practically be avoided by selective quarrying. These sources should not be listed as sources from which satisfactory material can be obtained unless much additional service record data are available to justify so doing and unless a method of inhibiting the expansion is devised.

POTENTIAL ALKALI REACTIVITY OF CARBONATE ROCK FROM SIX QUARRIES

INTRODUCTION

1. Recognition of the potential alkali reactivity of some carbonate rocks when the rocks are used as concrete aggregate has aroused interest in the development of methods for predicting the behavior of these materials. The work described in this report was undertaken to investigate the parameters that are believed to indicate potential reactivity and to seek interrelations among them.

2. Forty-one samples of rock from six quarries in Virginia and Kentucky were studied. Rock from five of the quarries had been investigated for use as concrete aggregate by the U. S. Army Engineer District, Huntington,[1] before evaluation for potential carbonate rock reactivity was included in aggregate investigational procedures. The rock from the sixth quarry had not been tested. Investigations of aggregate sources consisting of or including substantial amounts of carbonate rock now involve evaluation of the rock for potential alkali-carbonate reactivity. A description of the procedures for such evaluation will be included in the next revision of Appendix II of EM 1110-2-2000[2] (see Appendix A).

3. Pertinent data concerning the samples are given in table 1. Samples HUN-2 G-1 through -5 were from the five previously investigated sources.[1]

PROCEDURES

4. Each of the 41 samples was represented by one blocky or tabular piece of carbonate rock roughly equivalent in size to a particle of 6-in.* aggregate. Each piece of rock was intended to be typical of an individual rock ledge. The ledges ranged from 4 to 80 ft thick (table 1).

5. Each piece of rock was examined visually, and a saw cut was made normal to the direction of bedding. Fig. 1 shows a typical sawed surface and the sampling plan that was used in all cases to obtain the

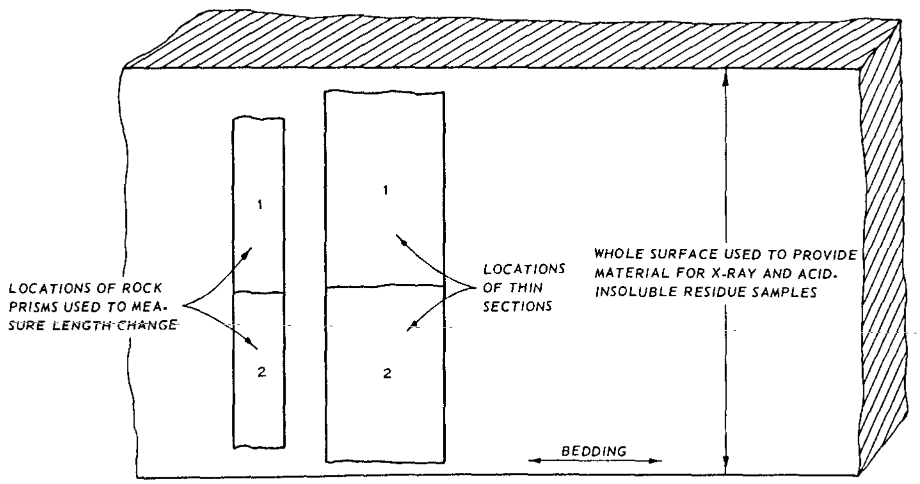

Fig. 1. Sampling plan on sawed surface of rock sample

* A table of factors for converting British units of measurement to metric units is presented on page vii.

laboratory samples. As fig. 1 indicates, an effort was made to obtain samples from each piece of rock so that all of the results would, as nearly as possible, represent similar material.

Length-Change Determinations

6. Two rock prisms, approximately 1/4 by 1/4 by 1-1/4 in. in dimension, were cut from each sample in the orientation shown in fig. 1. The prisms were stored in distilled water until they attained a stable length; they were then stored in 40 ml of 1 N sodium hydroxide (NaOH) solution in small plastic bottles for three years. Length-change measurements were made periodically with a micrometer during this time span following a procedure essentially similar to that subsequently standardized as CRD-C 146-67.[3]

7. A slice about 1 in. thick was cut from samples HUN-2 G-4(A through D) parallel to the first saw cut. The proper location for a pair of length-change specimens was drawn on the slice to correspond with the first pair that was tested. These pieces were sent to the Virginia Highway Research Council (VHRC) for length-change testing of small rock specimens and interlaboratory comparison on similar specimens. They were tested in accordance with what is now the standard procedure.[3]

8. Due to the rapid and large expansion of the two prisms representing sample HUN-2 G-4(A), three additional prisms were prepared and tested; prism No. 2 of this set broke after 14 days in NaOH solution. It was then ground and examined by X-ray methods as a tightly packed powder.

9. The procedure for determining length change of all of the specimens in the WES Concrete Division antedated the present test method (CRD-C 146-67)[3] and differed from it as follows:

- *a.* CRD-C 146-67 calls for a minimum of 35 ml of NaOH solution per specimen; 20 ml per specimen was used.
- *b.* CRD-C 146-67 specifies changing the solution after each six months of testing; the solutions in this investigation were not changed during the testing period.

10. Three additional specimens were prepared from sample HUN-2 G-6F(1) and from sample HUN-2 G-6J and were tested for about one year. This testing was conducted in accordance with CRD-C 146-67.

Composition of Samples

11. A representative portion of each sample was reduced by grinding to pass a No. 325 (44μ) sieve and was examined as a tightly packed powder with an X-ray diffractometer for mineralogical composition, including amount of dolomite. The amount of dolomite was determined by the method of Tennant and Berger[4] for all samples containing 10% or more dolomite in the carbonate portion of the rock.

Acid-Insoluble Residue

12. A representative portion of each sample was powdered and dissolved in 6 N hydrochloric acid (HCl). Weighings were made before and after this treatment to permit calculation of the percentage of acid-insoluble residue. The insoluble portions of samples HUN-2 G-6(A through J) were X-rayed in the air-dry state, after treatment with glycerol, and after heating to 500 C for 1 hr. The insoluble portions of two of these samples were also X-rayed after being heated to 700 C.

Absorption and Specific Gravity Data

13. Approximately half of each piece of rock was used to determine absorption and specific gravity according to CRD-C 107,[3] except that a 7-day rather than a 24-hr soaking period was used.

Thin Section Examinations

14. At least two thin sections were prepared from each sample from an area adjacent to that used for the length-change specimens (see fig. 1). Each thin section was examined with a polarizing microscope to determine composition and texture. These data and those obtained from examination of sawed and etched surfaces permitted classification of each sample into one of the six categories. The criterion proposed by Hadley[5] was applied to evaluate texture. This criterion is quoted as follows:

> The matrix of the rock is composed of micro-crystalline calcite with abundant admixed clay material. Scattered randomly throughout the matrix are small rhombs of dolomite and occasional pieces of silt-sized quartz and feldspar.

The term partially reactive was used to designate those rocks that contained areas of both reactive and nonreactive texture.

Other Examinations

15. One of the sawed surfaces of each rock sample was etched in dilute HCl. The etched surface was inspected visually and with a stereomicroscope. The information gained concerning texture and amount and distribution of dolomite and of acid-insoluble residue was considered along with thin section data in classifying the samples by rock type and texture.

X-Ray Equipment

16. All X-ray patterns were made with a diffractometer using nickel-filtered copper radiation.

TEST RESULTS

17. The criteria established for detecting potentially reactive carbonate rocks, presented as Appendix A to this report and scheduled for inclusion in the next revision of Appendix II of EM 1110-2-2000,[2] were used as the basis for classifying the rocks included in this study.

18. The data in table 1 show the ledge from which each sample was obtained at each of the six quarries. The thickness of each ledge and the estimated percentage of the total production represented by each sample are also indicated.

19. Table 2 shows length-change data for each specimen for selected time periods between 7 days and 3 years. The VHRC data for samples HUN-2 G-4 (A through D) are included in this table.

20. Physical and chemical data are presented in table 3 by sample source. The samples from each source are grouped by length-change data into those that expanded 0.1% or more by 84 days of test, those that expanded 0.1% or more after 84 days of test, and nonexpanders or those that expanded less than 0.1%.

21. In this investigation, two length-change specimens were chosen from vertically adjoining positions on a diamond-saw cut normal to the bedding of each rock sample,* with the intention of representing as much as possible of the stratigraphic interval in the sample by these specimens. A sample was classified as expansive if a single test specimen expanded as much as 0.1% at any age. Subsequent experience has led to modifications that are believed to be improvements in the procedures for sampling

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* Additional length-change specimens of HUN-2 G-4A, G-6F(1), and -6J were taken later because either the texture or composition was not that expected from the length-change results.

and evaluation. The practice now followed is to sort the whole petrographic sample into lithologic varieties and prepare surfaces sawed normal to bedding of each variety suspected of containing dolomite. The surfaces are etched with dilute hydrochloric acid and examined visually and with a stereomicroscope for variations in composition and texture. If a lithologic variety appears to be homogeneous, as represented in the etched surface or surfaces, and contains detectable dolomite, a pair of length-change cylinders is taken side by side normal to bedding rather than from vertically adjoining positions. A variety that is abundant in the sample will probably be represented by several pairs of specimens, each pair from a different piece. If the etched surface appears to be inhomogeneous, and dolomite, calcite, and insoluble residue are not uniformly distributed, a pair of specimens is taken side by side to represent each significant dolomite-containing variation in the rock. Although this change in procedure results, in some instances, in a reduction of the vertical interval sampled in homogeneous lithologic varieties, much more information is now obtained before any lithologic variety is sampled, and rock with significant vertical or lateral variation is likely to be represented by more specimen locations than would have been the case in the investigation described in this report. In evaluating the results of the rock cylinder test, the data for each pair of specimens taken side by side are averaged rather than considered separately, since they are believed to represent normal variation in one sample. If individual values for a pair of specimens show significant differences, then additional specimens are prepared and tested. In apparently homogeneous lithologic varieties, the additional specimens are expected to confirm the results of one of the specimens, or occupy the interval between the results of the initial pair. In inhomogeneous varieties, the additional specimens are expected to confirm the existence of real differences.

22. The expansion data were classified in three groups, and relevant data on the range in properties of these rocks associated therewith are as follows:

	Expansion Group		
	0.1% or More by 84 Days	0.1% or More at Age Greater than 84 Days	Less than 0.1% at All Ages
Samples (for each quarry in order of decreasing rate of expansion)	1-E, H, D	1-I, B, G	1-A, C,** F
	2-none	2-none	2-A, B, C
	3-F	3-C, A	3-B, D, E,** G*
	4-A, D, B	4-C	4-none
	5-F, G	5-B	5-A, C, D,** E**
	6-B, E, H, D, J*	6-A, C, F-1*	6-F-2,** G, I
Dolomite, % of carbonate	0 to 50	0 to 89	0 to 56
Acid-insoluble residue, %	1.7 to 31.3	1.6 to 28.6	0.4 to 44.6
Absorption (SSD), %	0.1 to 1.2	0.0 to 0.9	0.0 to 0.4
Texture: total number reactive	7	0	0
total number partially reactive	4	4	1
total number nonreactive	3	6	16

* Sample contained no detectable dolomite.
** Sample contained only traces of dolomite.

23. The classification of HUN-2 G-6F(1) and -6J as expansive was unexpected since nondolomitic

rocks are generally not considered to be expansive. In a previous investigation of reactive nondolomitic carbonate rocks, none were found that were expansive.[6]

24. The textures of HUN-2 G-6F(1) and -6J were classed as nonreactive since they ranged from patches of lithographic limestone (limy mud) scattered in a matrix of clear calcite to patches of clear calcite scattered in a matrix of limy mud with no detectable dolomite. The length-change data in table 2 for three additional specimens from each sample show that the expansion was not reproducible. It was not possible to determine if the expansions of prism No. 2 of each sample were real or were the results of an error in establishment of an original reference length. It is probable that the expansion was real and represented limited areas in the two rocks that were actually reactive. The rock as a whole was not believed to be reactive in either case. The practice of presenting length-change data as averages of pairs of specimens would have prevented classification of either of these specimens as expansive.

25. The results of inspection of the acid-etched rock surfaces and the results of thin section studies to determine the type of texture possessed by each sample served as the basis for classifying the samples according to the six rock categories established for this purpose. The following tabulation shows the groupings that were made and which of the three expansion categories each fell into:

Rock Category	Sample HUN-2 G- Expansive By 84 Days	Sample HUN-2 G- Expansive After 84 Days	Sample HUN-2 G- Nonexpansive
Type I—Medium-grained rock with many fossils in matrix of limy mud. Classified as nonreactive texture		1I	1A
Type III—Patches of medium-grained subhedral grains of dolomite in matrix of nondolomitic limy mud. Classified as nonreactive texture			2B
Type IV—Sandy carbonate rock. 2C has matrix of limy mud balls and clear calcite. 3F has matrix of limy mud. 5C has matrix of small crystals of calcite and dolomite and a few limy mud balls. Classified as nonreactive texture	3F		2C, 5C
Type V—Fine-grained, calcitic dolomite rock. Classified as nonreactive texture		3A, 3C, 4C	
Type VI—Light-colored, fine-grained oolitic limestone. Classified as nonreactive texture			3B, 3D, 3E, 5A
Type II—Dark-colored, lithographic (= limy mud) carbonate rocks. Classified as:			
Reactive texture	1E, 1H, 4D, 5F, 5G, 6B, 6E		

(Continued)

Rock Category	Sample HUN-2 G- Expansive By 84 Days	After 84 Days	Non-expansive
Type II–(Continued)			
Partially reactive texture	1D, 4B, 6D, 6H	1B, 1G, 6A, 6C	2A
Nonreactive texture	4A, 6J	5B, 6F-1	1C, 1F, 3G, 5D, 5E 6F-2, 6G, 6I
Total	14	10	17

The ten underscored samples in the tabulation above are the ones that had unexpected behavior in the length-change test. These anomalies will be discussed in a later section.

26. The compositions of the insoluble residues of samples A through J of HUN-2 G-6 are shown in the following tabulation:

Sample HUN-2 G-6	Composition of Insoluble Residue by X-ray Analysis: Clay Minerals: Chlorite	Clay-Mica	Kaolinite	Nonclay Minerals: Quartz	Feldspar	Hematite
A	Present	Present	Absent	Present	Present	Present
B	Present	↓	Absent	↓	Absent	Present
C	Present	↓	Absent	↓	Absent	Absent
D	Absent	↓	Present	↓	Present	Absent
E	Present	↓	Absent	↓	Absent	Present
F-1	↓	↓	↓	↓	Present	Absent
F-2	↓	↓	↓	↓	Present	Absent
G	↓	↓	↓	↓	Present	Present
H	↓	↓	↓	↓	Present	Present
I	↓	↓	↓	↓	Absent	Present
J	↓	↓	↓	↓	Present	Absent

A small amount of kaolinite may have been present in the ten samples where it is reported as absent; if so, it was not present in amounts detectable by X-ray analysis.

27. The mechanism that is generally believed to be responsible for the expansion of reactive dolomitic carbonate rocks is the dedolomitization reaction of dolomite in an alkaline environment. Brucite ($Mg(OH)_2$), a crystalline product of this reaction, has been identified by X-ray analysis of other reacted rocks. There was no detectable brucite in the X-ray pattern of pulverized rock prism No. 2 of sample HUN-2 G-4A after 14 days in NaOH. However, this does not conclusively prove its absence in this case since this X-ray examination is best made on a solid surface of reacted rock.

28. Table 4 provides data on testing of different samples of rocks from the same quarries by the Virginia Highway Research Council (VHRC) and by the WES Concrete Division (CD). The CD values for weighted average expansions at two ages should provide some measure of whether reactive rock in a quarry is adequately diluted by nonreactive rock to reduce expansion to a safe level. Values are also given to indicate what percentage of the estimated production expanded 0.1% or more at two ages. Possible remedial treatments to minimize expansions are considered in the last column.

29. Fig. 2 is a graphical presentation of the average length change of each ledge at two ages.

Expansions or contractions greater than 0.40% are not to scale; instead, they are indicated by numerical values.

DISCUSSION OF RESULTS

30. The criteria for recognizing potentially reactive dolomitic carbonate rocks are based on composition, texture, and amount of expansion in the length-change test (see Appendix A). Composition that indicates potentially reactive rock is described in Appendix A as "substantial amounts of dolomite and calcite in the carbonate portion of the rock and significant amounts of acid-insoluble residue consisting largely of clay." Characteristic texture that indicates reactive rock was described earlier. Expansion of 0.1% or more by 84 days in the length-change test indicates potentially reactive rocks.

31. The samples in this study were grouped on the basis of the length-change data into those that expanded 0.1% or more by 84 days, those that expanded 0.1% or more after 84 days, and those that did not expand as much as 0.1% during the test period. This grouping was made in an attempt to determine if the existing criteria successfully separated the potentially reactive from the nonreactive rocks. These criteria, as well as others such as absorption, specific gravity, etc., were examined and other comparisons were made.

32. In general, the criteria (Appendix A) are successful in distinguishing between potentially reactive and nonreactive materials for the types of rocks they were designed to delineate. There were, however, some exceptions to this that have been mentioned in earlier paragraphs. Most of the ten exceptions failed to behave in the way expected from their composition and texture:

- *a.* One sample (G-2(A)) expected to expand did not, although it contained 27% dolomite in the carbonate portion and 19% of acid-insoluble material.
- *b.* Four samples containing less than 15% dolomite in the carbonate portion and accordingly not expected to expand did expand (G-1(I), G-5(B), G-4(A), and G-3(F)).
- *c.* Three samples containing more than 70% dolomite in the carbonate portion and not expected to expand did so (G-3(A), G-3(C), and G-4(C)).
- *d.* Two samples (6(F)(1) and 6(J)) expanded although they contained no detectable dolomite.

These results are regarded as misleading.

33. In similar work for some carbonate rocks from Canada, expansive rocks of similar unusual compositions were reported.[7]

34. None of the comparisions made of rock expansion against any of the other rock properties that were measured or against combinations of these properties provided any new or improved methods of anticipating potential reactivity (measured as expansion).

35. The group of ten rocks that expanded 0.1% or more after 84 days of testing showed maximum expansion of 0.57%, although most were less than 0.4%. Additional work is needed to evaluate the significance of such delayed slow expansion on the behavior of concrete.

36. When test data on presumably homogeneous materials fail to agree, as was the case for some of the rocks tested during this investigation, the possibility of sampling error must be considered. Even though efforts are made to ensure that all of the data for any one sample represent similar rock, there is the possibility that some of the unexpected results are due to nonhomogeneity within a sample. If such possibilities do arise, the dolomite and the acid-insoluble residue contents should be checked by comparison of indications from X-ray work, by comparison of thin sections, and by the appearance of acid-etched sawed surfaces. If the material is essentially homogeneous, each of these methods should indicate similar results.

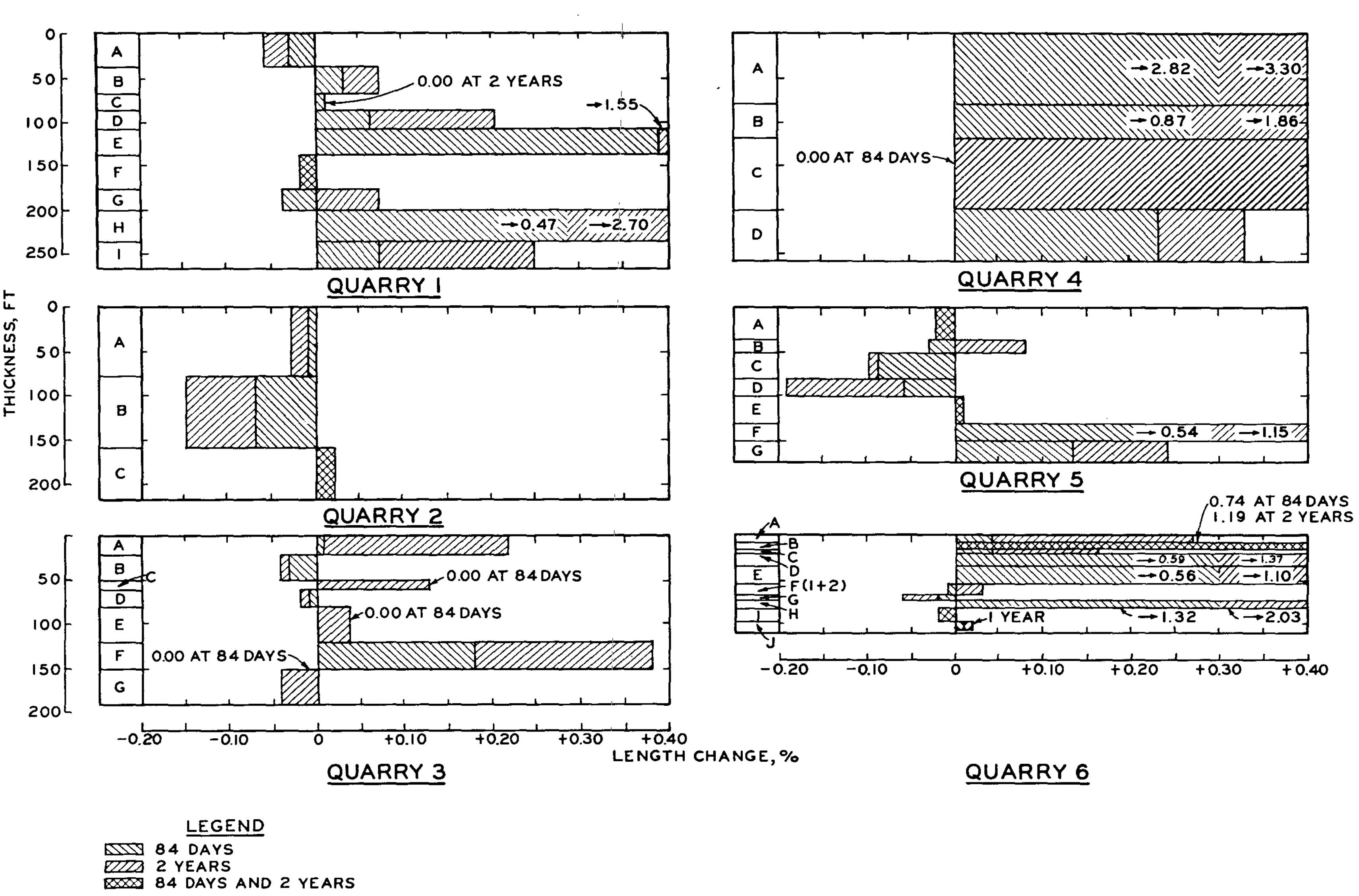

Fig. 2. Length change (CD) at 84 days and 2 years

37. The samples that were identified as exhibiting unexpected results in the tabulation in paragraph 25 are discussed below:

a. *Sample HUN-2 G-1(I).* This Type I rock was expansive after 84 days, whereas the other Type I rock, HUN-2 G-1(A), was not expansive. The two samples had low dolomite contents in a matrix of limy mud; sample HUN-2 G-1(I) contained 13.6% acid-insoluble residue, while HUN-2 G-1(A) contained only 2.6%. Rocks with dolomite contents of 10% or less in their carbonate portions are not usually considered expansive.

b. *Sample HUN-2 G-2(A).* This was a Type II rock classified as having a partially reactive texture. Since it contained 18.2% acid-insoluble residue and 27% dolomite in its carbonate fraction, it was expected to be expansive. However, it did not expand.

c. Four of the samples classified as Type II showed unexpected expansion.

(1) *Samples HUN-2 G-5(B), -6(F-1), and -6(J).* Sample HUN-2 G-5(B) contained less than 10% dolomite; there was no detectable dolomite in the other two samples. The late expansion of HUN-2 G-5(B) may have been real, but that of the other two samples was considered misleading, as discussed in paragraph 24.

(2) *Sample HUN-2 G-4(A).* The expansion of seven prisms was rapid and high (table 2). This sample was the most reactive of those tested as judged by amount of expansion. It was not expected to be expansive because it had a low dolomite content (about 15% of the carbonate portion of the rock). Also, none of its other physical properties indicated that this would be such an expansive rock.

d. *Sample HUN-2 G-3(F).* This was a Type IV sandy carbonate rock that was expansive in less than 84 days; it contained 31.3% acid-insoluble residue, much of which was grains of quartz. Rocks with such high sand contents and low amounts of dolomite (<10% of carbonate portion of rock) are not usually considered expansive. This rock differed from the other two Type IV sandy rocks (HUN-2 G-2(C), -5(C)), which were not expansive, as follows: sample HUN-2 G-2(C) had a matrix of limy mud balls and clear calcite; sample HUN-2 G-5(C) had a matrix of limy mud balls, clear calcite, and some small dolomite crystals; sample HUN-2 G-3(F) had a matrix of limy mud without any clear calcite.

e. *Samples HUN-2 G-3(A), -3(C), and -4(C).* These were Type V calcitic dolomites having dolomite contents of 78, 72, and 89% in their carbonate portions. They were slowly expansive, requiring from six months to a year to expand as much as 0.1%. The maximum expansion measured was 0.57% for HUN-2 G-4(C) after two years of test. Rocks of the composition of these three are not usually considered expansive.

38. The variation in length change for two specimens taken one from above the other from the same rock, as was done with all of the original pairs in this study, has also been observed by other investigators. An example of this is seen in table 2 for specimens D-1 and D-2 of HUN-2 G-4, which were tested by the VHRC.

39. CD and VHRC length-change data for pairs of specimens of HUN-2 G-4(A through D) that were intended to be identical can be compared in table 2. The lack of better agreement for about half the pairs is attributed to unexpected variation in the rock between supposedly identical specimens.

CONCLUSIONS

40. Since the criteria of texture and composition did not in every case detect potentially reactive dolomitic carbonate rocks for the present group of 41 samples, it appears that any carbonate rock that contains detectable dolomite in a matrix of limy mud should be subjected to the length-change test if it is being considered for use as concrete aggregate.

41. The evaluation of carbonate rocks as potentially reactive should be based on length-change data

that are averages of two specimens of a homogeneous variety rather than on values for single specimens. These specimens should preferably be taken in horizontally adjoining positions normal to bedding rather than from vertically adjoining positions, chosen after examination of acid-etched rock surfaces. When this examination indicates significant variations in texture or composition or both, then as many pairs of specimens should be tested as are necessary to represent each significant variation in the rock. When results for a pair of specimens are not similar, additional specimens should be obtained and tested to determine the reason for the nonsimilarity.

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Table 1

Identification of Samples

CD Serial No.	Field Identification: Sample No.	Field Identification: Estimated Ledge Thickness, ft	Estimated Percentage of Total Production
HUN-2 G-1A	A	40	13
1B	B	30	10
1C	C	20	7
1D	D	20	7
1E	E	30	10
1F	F	40	13
1G	G	20	7
1H	H	40	13
1I	I	30	10
2A	A	80	35
2B	B	80	35
2C	C	60	25
3A	A	20	10
3B	B	30	15
3C	C	10	5
3D	D	20	10
3E	E	40	20
3F	F	30	15
3G	G	40	20
4A	A	80	30
4B	B	40	15
4C	C	80	30
4D	D	60	20
5A	A	40	20
5B	B	15	8
5C	C	30	16
5D	D	20	10
5E	E	30	16
5F	F	20	10
5G	G	25	14
6A	1	8	7
6B	2	6	5
6C	3	4	4
6D	4	15	14
6E	5	20	18
6F	6	12	11
6G	7	5	5
6H	8	8	7
6I	9	15	14
6J	10	10	9

Table 2

Concrete Division (CD) and Virginia Highway Research Council (VHRC) Length-Change Data on Rock Specimens Stored in 1 N NaOH Solution*

Sample Identification		Length Change, %, at Ages Shown Below									
		7 Days	14 Days	28 Days	56 Days	84 Days	6 Months	9 Months	1 Year	2 Years	3 Years
HUN-2 G-1	A-1	−0.02	−0.02	−0.02	0.01	0.00	0.00	−0.01	0.02	0.01	−0.01
	A-2	−0.02	−0.06	−0.06	−0.08	−0.06	−0.06	−0.08	−0.10	−0.12	−0.09
	B-1	0.00	−0.01	0.02	0.01	0.06	0.11	0.13	0.14	0.14	**
	B-2	−0.01	−0.02	−0.01	−0.02	0.00	−0.01	0.00	−0.01	0.00	0.01
	C-1	0.01	0.02	0.02	−0.02	−0.01	0.02	0.01	0.02	0.01	0.01
	C-2	0.00	0.00	−0.01	0.00	0.02	0.00	−0.02	0.00	−0.01	0.00
	D-1	−0.02	0.00	0.02	0.04	0.10	0.20	0.24	0.24	0.35	**
	D-2	0.02	0.01	0.02	−0.01	0.02	0.02	0.02	0.03	0.04	0.05
	E-1	−0.02	0.01	0.23	0.48	0.72	1.42	1.86	2.11	2.58	**
	E-2	−0.02	0.00	−0.02	0.06	0.06	0.27	0.28	0.32	0.52	**
	F-1	−0.01	−0.02	−0.01	−0.02	−0.02	−0.02	−0.03	−0.02	−0.01	0.00
	F-2	0.02	0.01	−0.02	−0.02	−0.01	−0.02	−0.02	0.00	−0.02	−0.02
	G-1	−0.02	−0.01	−0.04	0.00	−0.05	−0.04	−0.02	−0.02	0.02	0.05
	G-2	−0.02	−0.04	−0.05	−0.05	−0.03	0.03	0.05	0.06	0.12	**
	H-1	0.02	0.03	0.20	0.38	0.65	1.17	1.66	2.02	2.78	**
	H-2	0.01	−0.01	0.01	0.14	0.29	0.74	1.22	1.55	2.61	**
	I-1	0.02	0.01	0.02	0.02	0.05	0.07	0.14	0.16	0.25	**
	I-2	0.00	0.02	0.02	0.08	0.09	0.11	†	--	--	--
HUN-2 G-2	A-1	0.02	0.01	0.00	−0.01	0.00	0.02	0.02	0.00	0.01	0.01
	A-2	0.00	0.00	0.01	0.02	−0.02	0.03	−0.02	−0.05	−0.07	−0.06
	B-1	−0.02	−0.05	−0.08	−0.11	−0.12	−0.17	−0.19	−0.24	−0.24	−0.23
	B-2	−0.01	0.00	−0.01	−0.01	−0.02	−0.02	−0.02	−0.06	−0.06	−0.05
	C-1	0.01	0.01	0.03	0.05	0.03	0.04	0.04	0.05	0.06	0.05
	C-2	0.02	−0.01	−0.02	0.02	0.02	0.02	−0.02	−0.05	−0.03	−0.01
HUN-2 G-3	A-1	−0.02	−0.01	−0.01	−0.05	0.02	0.03	0.06	0.08	0.16	**
	A-2	−0.02	−0.01	−0.04	−0.07	0.00	0.02	0.09	0.12	0.29	**
	B-1	−0.02	−0.02	−0.02	−0.05	−0.05	−0.02	−0.02	−0.01	−0.01	−0.02
	B-2	0.01	0.01	−0.01	−0.01	−0.01	−0.04	−0.02	−0.03	−0.07	−0.05
	C-1	−0.01	0.00	0.01	0.01	0.02	0.06	0.05	0.10	0.24	**
	C-2	−0.01	−0.02	−0.02	−0.04	−0.02	−0.01	0.01	0.04	0.03	0.08
	D-1	−0.04	−0.04	−0.02	−0.02	−0.01	−0.02	−0.02	−0.05	−0.02	−0.04
	D-2	−0.01	0.00	0.00	−0.02	−0.01	−0.01	−0.02	−0.02	−0.03	−0.01
	E-1	−0.01	−0.02	−0.03	−0.04	−0.04	−0.02	−0.02	−0.01	−0.01	−0.01
	E-2	0.03	0.05	0.06	0.04	0.04	0.06	0.06	0.08	0.08	0.06
	F-1	0.05	0.03	0.05	0.05	0.03	0.02	0.00	0.02	0.04	0.04
	F-2	0.05	0.12	0.22	0.26	0.33	0.54	0.62	0.66	0.72	**
	G-1	−0.03	−0.02	0.01	0.01	−0.01	0.01	−0.02	−0.03	−0.02	0.00
	G-2	−0.02	−0.01	−0.02	−0.03	0.01	−0.01	−0.04	−0.05	−0.06	−0.02

(Continued)

* All CD data unless otherwise indicated.

** No measurements made after 2 years if specimen expanded as much as 0.10%.

† Readings discontinued because specimen broke.

Table 2 (Continued)

Sample Identification		Length Change, %, at Ages Shown Below 7 Days	14 Days	28 Days	56 Days	84 Days	6 Months	9 Months	1 Year	2 Years	3 Years
HUN-2 G-4††	A-1	−0.01	0.13	0.61	1.37	1.82	2.18	2.25	2.25	2.25	**
	A-2	0.22	1.04	†	--	--	--	--	--	--	--
VHRC	A-1	0.01	0.14	0.69	†	--	--	--	--	--	--
VHRC	A-2	0.00	0.14	0.72	2.18	3.16	3.77	3.83	3.88	‡	‡
	A-3	‡	0.26	1.37	3.10	3.71	3.88	3.93	3.95	3.97	**
	A-4	‡	0.18	0.90	2.44	3.16	3.24	3.31	3.31	3.35	**
	A-5	‡	0.14	0.81	2.51	2.57	3.57	3.60	3.60	3.62	**
	B-1	−0.01	0.00	−0.01	0.03	0.06	0.60	1.64	1.74	1.86	**
	B-2	−0.01	−0.02	0.04	0.49	1.68	2.09	†	--	--	--
VHRC	B-1	0.00	0.02	0.10	0.70	1.64	2.96	3.14	3.33	‡	--
VHRC	B-2	0.00	0.02	0.06	0.52	1.31	2.71	3.02	3.15	‡	--
	C-1	−0.02	−0.01	0.00	0.00	0.02	0.14	0.32	0.38	0.57	**
	C-2	−0.01	−0.02	−0.03	−0.03	−0.02	0.05	0.10	0.13	0.22	**
VHRC	C-1	−0.01	−0.01	−0.04	−0.05	0.02	0.78	1.13	1.27	‡	--
VHRC	C-2	0.02	−0.01	−0.04	−0.06	0.01	0.80	1.07	1.20	‡	--
	D-1	−0.01	−0.01	0.00	0.00	0.01	0.00	−0.02	−0.02	−0.03	−0.02
	D-2	0.05	0.14	0.27	0.38	0.45	0.48	0.63	0.64	0.69	**
VHRC	D-1	0.03	0.07	0.10	0.14	0.18	0.26	0.33	2.55	‡	--
VHRC	D-2	−0.01	0.00	−0.02	−0.04	−0.03	−0.04	−0.02	−0.05	‡	--
HUN-2 G-5	A-1	−0.02	−0.01	0.00	−0.01	−0.02	0.02	−0.01	0.00	−0.02	−0.03
	A-2	−0.02	−0.03	−0.02	−0.03	−0.02	−0.04	−0.03	−0.02	−0.03	−0.03
	B-1	0.02	0.00	0.02	0.02	0.02	0.02	0.05	0.05	0.11	**
	B-2	−0.01	−0.01	0.01	−0.08	−0.08	−0.05	0.00	0.02	0.06	0.08
	C-1	−0.01	−0.02	−0.02	−0.02	−0.03	−0.04	−0.03	−0.05	−0.01	†
	C-2	−0.05	−0.09	−0.13	−0.15	−0.15	−0.17	−0.24	−0.24	−0.20	−0.16
	D-1	‡	−0.07	−0.06	−0.09	−0.10	0.06	−0.24	−0.25	−0.30	‡
	D-2	0.01	0.01	−0.04	−0.04	−0.02	−0.01	−0.03	−0.03	−0.08	−0.03
	E-1	0.03	0.05	0.06	0.01	0.08	0.06	0.03	0.04	0.06	0.07
	E-2	−0.02	−0.05	−0.02	−0.04	−0.06	−0.04	−0.05	−0.06	−0.04	−0.04
	F-1	0.04	0.05	0.25	0.57	0.92	1.46	1.75	1.82	1.87	**
	F-2	−0.02	0.00	−0.02	0.10	0.17	0.33	0.40	0.42	0.43	**
	G-1	−0.02	−0.04	0.00	0.02	0.04	0.03	0.05	0.05	0.05	0.06
	G-2	−0.02	−0.01	0.00	0.11	0.22	0.33	0.43	0.44	0.44	**

(Continued)

** No measurements made after 2 years if specimen expanded as much as 0.10%.
† Readings discontinued because specimen broke.
†† The use of identical numbers in the two laboratories indicates specimens that are intended to be identical.
‡ No reading made.

Table 2 (Concluded)

Sample Identification		Length Change, %, at Ages Shown Below									
		7 Days	14 Days	28 Days	56 Days	84 Days	6 Months	9 Months	1 Year	2 Years	3 Years
HUN-2 G-6	A-1	‡	0.01	−0.03	0.02	0.06	0.13	0.23	0.23	0.21	**
	A-2	‡	0.02	0.01	0.03	0.02	0.09	0.17	0.14	0.33	**
	B-1	‡	0.07	0.08	0.20	0.34	0.68	0.90	0.93	1.19	**
	B-2	‡	0.16	0.39	0.74	1.14	1.72	†	--	--	--
	C-1	‡	0.03	0.03	0.04	0.05	0.04	0.09	0.09	0.13	**
	C-2	‡	0.03	0.02	0.07	0.04	0.09	0.08	0.09	0.18	**
	D-1	‡	0.10	0.34	0.69	0.90	1.10	1.34	1.43	1.67	**
	D-2	‡	0.02	0.06	0.18	0.28	0.49	0.70	0.76	1.07	**
	E-1	‡	0.18	0.33	0.40	0.50	0.65	0.80	0.79	0.96	**
	E-2	‡	0.13	0.22	0.43	0.60	0.79	0.91	1.04	1.25	**
	F(1)-1	‡	−0.01	−0.03	−0.01	0.00	−0.02	−0.02	−0.02	−0.03	0.03
	F(1)-2	‡	0.03	0.06	0.06	0.05	0.07	0.11	0.08	0.15	**
	F(1)-3	0.00	−0.02	−0.02	0.00	−0.02	−0.02	−0.01	−0.05	--	--
	F(1)-4	−0.04	−0.04	−0.06	−0.07	−0.05	−0.09	−0.06	−0.08	--	--
	F(1)-5	−0.04	−0.02	0.00	−0.01	−0.06	−0.06	−0.05	−0.06	--	--
	F(2)-1	‡	0.01	0.02	0.00	0.01	−0.01	0.01	0.02	0.02	0.02
	F(2)-2	‡	−0.03	0.02	−0.01	−0.01	−0.03	−0.07	−0.05	−0.02	−0.08
	G-1	‡	0.02	−0.02	−0.02	−0.03	−0.02	−0.01	−0.02	−0.02	0.00
	G-2	‡	−0.01	−0.04	−0.06	−0.02	−0.07	−0.06	−0.06	−0.09	−0.07
	H-1	‡	0.22	0.75	1.78	2.33	3.02	3.42	3.50	3.57	**
	H-2	‡	0.05	0.15	0.16	0.31	0.39	0.45	0.46	0.49	**
	I-1	‡	0.00	0.01	−0.01	−0.02	−0.04	−0.01	0.01	0.01	0.01
	I-2	‡	−0.02	−0.02	−0.02	−0.02	−0.07	−0.07	−0.05	−0.05	−0.03
	J-1	‡	†	--	--	--	--	--	--	--	--
	J-2	‡	0.08	0.11	0.10	0.11	0.11	0.10	0.12	0.12	**
	J-3	0.00	−0.01	0.01	−0.02	−0.02	−0.04	−0.02	−0.03	--	--
	J-4	0.00	−0.02	−0.07	−0.04	−0.05	−0.07	−0.08	−0.01	--	--
	J-5	0.00	−0.01	0.02	−0.01	−0.01	−0.03	−0.02	−0.01	--	--

** No measurements made after 2 years if specimen expanded as much as 0.10%.
† Readings discontinued because specimen broke.
‡ No reading made.

Table 3

Physical and Chemical Data on Six Carbonate Rock Samples

Sample Identification	Dolomite, % of Carbonate Portion of Rock*	Acid-Insoluble Residue, %	Absorption (SSD), %**	Bulk Specific Gravity (SSD)	Length Change† of Rock Specimens in % After 84 Days	2 Years	Expansion Group	Texture and Remarks
HUN-2 G-1E	12	9.6	0.2	2.71	0.39	1.55	Expansive by 84 days††	Reactive texture. One specimen expanded 0.23% by 28 days
1H	30	12.2	0.4	2.71	0.47	2.70	↓	Reactive texture. One specimen expanded 0.20% by 28 days
1D	<10	9.2	0.4	2.80	0.06	0.20	↓	Partially reactive texture. One specimen expanded 0.10% by 84 days
1I	10	13.6	0.6	2.70	0.07	0.25	Expansive after 84 days††	Nonreactive texture. One specimen expanded 0.17% by 112 days
1B	19	3.7	0.1	2.72	0.03	0.07	↓	Partially reactive texture. One specimen expanded 0.11% by 168 days
1G	27	16.3	0.1	2.72	−0.04	0.07	↓	Partially reactive texture. One specimen expanded 0.12% by 2 years
1A	<10	2.6	0.1	2.70	−0.03	−0.06	Nonexpansive	Nonreactive texture
1C	trace	0.4	0.1	2.70	0.01	0.00	↓	Nonreactive texture
1F	<10	2.8	0.1	2.69	−0.02	−0.02	↓	Nonreactive texture
2A	27	18.2	0.1	2.72	−0.01	−0.03	Nonexpansive	Partially reactive texture
2B	30	2.0	0.3	2.72	−0.07	−0.15	↓	Nonreactive texture
2C	<10	27.0	0.1	2.69	0.02	0.02	↓	Nonreactive texture
3F	<10	31.3	0.8	2.66	0.18	0.38	Expansive by 84 days††	Nonreactive texture. One specimen expanded 0.12% by 14 days
3C	72	16.4	0.7	2.75	0.00	0.13	Expansive after 84 days††	Nonreactive texture. One specimen expanded 0.11% by 336 days
3A	78	19.8	0.6	2.76	0.01	0.22	↓	Nonreactive texture. One specimen expanded 0.12% by 1 year

(Continued)

* Determined by X-ray method of Tennant and Berger.[4]
** Each specimen was soaked 7 days.
† Average of two specimens when possible except for samples 4A, 6F(1), and 6J; five specimens were measured for each of them.
†† Defined as one or more specimens of a set expanding as much as 0.10%.

Table 3 (Continued)

Sample Identification	Dolomite, % of Carbonate Portion of Rock	Acid-Insoluble Residue, %	Absorption (SSD), %	Bulk Specific Gravity (SSD)	Length Change of Rock Specimens in % After 84 Days	Length Change of Rock Specimens in % After 2 Years	Expansion Group	Texture and Remarks
HUN-2 G-3B	<10	0.6	0.2	2.70	−0.03	−0.04	Nonexpansive	Nonreactive texture
3D	<10	2.5	0.1	2.70	−0.01	−0.02	↓	Nonreactive texture
3E	trace	1.8	0.1	2.71	0.00	−0.04	↓	Nonreactive texture
3G	none	16.0	0.3	2.70	0.00	−0.04	↓	Nonreactive texture
4A	15	28.2	0.8	2.68	2.82	3.30	Expansive by 84 days††	Nonreactive texture. All five specimens expanded more than 0.1% by 14 days
4D	17	4.1	0.1	2.73	0.23	0.33	↓	Reactive texture. One specimen expanded 0.14% by 14 days
4B	11	29.4	1.2	2.68	0.87	1.86	↓	Partially reactive texture. One specimen expanded 0.49% by 56 days
4C	89	28.6	0.9	2.76	0.00	0.40	Expansive after 84 days††	Nonreactive texture. One specimen expanded 0.12% by 140 days
5F	12	14.7	0.3	2.70	0.54	1.15	Expansive by 84 days††	Reactive texture. One specimen expanded 0.25% by 28 days
5G	15	4.9	0.1	2.72	0.13	0.24	↓	Reactive texture. One specimen expanded 0.11% by 56 days
5B	<10	12.9	0.2	2.70	−0.03	0.08	Expansive after 84 days††	Nonreactive texture. One specimen expanded 0.11% by 2 years
5A	11	1.3	0.3	2.70	−0.02	−0.02	Nonexpansive	Nonreactive texture
5C	56	44.6	0.4	2.70	−0.09	−0.10	↓	Nonreactive texture
5D	trace	7.4	0.1	2.70	−0.06	−0.19	↓	Nonreactive texture
5E	trace	5.1	0.2	2.71	0.01	0.01	↓	Nonreactive texture

(Continued)

†† Defined as one or more specimens of a set expanding as much as 0.10%.

Table 3 (Concluded)

Sample Identification	Dolomite, % of Carbonate Portion of Rock	Acid-Insoluble Residue, %	Absorption (SSD), %	Bulk Specific Gravity (SSD)	Length Change of Rock Specimens in % After 84 Days	Length Change of Rock Specimens in % After 2 Years	Expansion Group	Texture and Remarks
HUN-2 G-6B	12	14.6	0.1	2.72	0.74	1.19	Expansive by 84 days††	Reactive texture. One specimen expanded 0.16% by 14 days
6E	23	16.1	0.5	2.71	0.56	1.10		Reactive texture. Both specimens expanded more than 0.10% by 14 days
6H	50	21.2	0.3	2.72	1.32	2.03		Partially reactive texture. One specimen expanded 0.22% by 14 days
6D	<10	10.4	0.2	2.71	0.59	1.37		Partially reactive texture. One specimen expanded 0.34% by 28 days
6J	none	1.7	0.1	2.71	0.01	--		Nonreactive texture. One specimen of four expanded 0.11% by 28 days
6A	23	6.5	0.1	2.72	0.04	0.27	Expansive after 84 days††	Partially reactive texture. Both specimens expanded more than 0.10% by 112 days
6C	<10	11.8	0.2	2.72	0.04	0.16		Partially reactive texture. One specimen expanded 0.10% by 112 days
6F-1	none	1.6	0.0	2.71	−0.02	0.06		Nonreactive texture. One specimen expanded 0.13% by 196 days
6F-2	trace	1.2	0.1	2.71	0.00	0.00	Nonexpansive	Nonreactive texture
6G	<10	0.7	0.1	2.70	−0.02	−0.06		Nonreactive texture
6I	<10	0.9	0.0	2.72	−0.02	−0.02		Nonreactive texture

†† Defined as one or more specimens of a set expanding as much as 0.10%.

Table 4

Comparative Evaluation of Rock from Six Quarries

Quarry No.	Evaluation by Previous Studies*	WES Concrete Division Data: Weighted Average Expansion in %** at 84 Days	2 Years	Percentage of Production that Expanded ≥0.1% by 84 Days	2 Years	Remedial Treatment
1	1 sample of 10 expanded 0.4% during 6 months testing	0.12	0.59	30	57	Avoid use of rock from this quarry since selective quarrying probably impractical
2	No expansion	−0.02	−0.07	none	none	None needed
3	Sample from 1 ledge expanded 0.4% by 6 months; other samples had low expansion	0.02	0.08	15	30	Probably none needed. However, selective quarrying could be used to avoid use of ledge F material
4	1 sample expanded 0.7% by 4 weeks	1.06	1.50	70	100	Avoid use of rock from this quarry
5	No data	0.05	0.13	24	32	Selective quarrying to avoid inclusion of ledge F and possibly ledge G
6	This material expanded 3%	0.34	0.67	53	69	Avoid use of rock from this quarry

* Personal communication from H. H. Newlon, Jr., of Virginia Highway Research Council.

** Calculated by combining the average length change for each ledge and the estimated production values.

APPENDIX A:

ALKALI-CARBONATE ROCK REACTIONS

1. GENERAL STATEMENT. The results of studies that have been reported indicate that four types of alkali-carbonate rock reaction can be recognized in concrete. A thorough review of research through 1964 is contained in reference 4f. It is possible that future work will show that some of these are merely different manifestations of the same reaction, shown by different rocks under a variety of circumstances. The types of reactions are discussed in the following paragraphs.

a. Reactions Involving Nondolomitic Carbonate Rocks. Some rocks that contain little or no dolomite may be reactive. The reaction is characterized by reaction rims that are visible along the borders of cross sections of aggregate particles; etching these cross-sectional surfaces with dilute hydrochloric acid reveals that the rims are "negative" rims, i.e. the reaction rim zone dissolves more rapidly than the interior of the particle. The evidence to date indicates that the reaction is not harmful to concrete and may even be beneficial.

b. Reactions Involving Dolomite or Highly Dolomitic Carbonate Rocks. The reaction of dolomite or highly dolomitic aggregate particles in concrete has been reported (ref 4c). The reaction was characterized by visible reaction rims on cross sections of the aggregate particles. When these cross-sectional areas of aggregate particles were etched with acid, the rimmed area dissolved at the same rate as the nonrimmed area. No evidence was reported that this reaction was damaging to concrete.

c. Reactions Involving Impure Dolomitic Carbonate Rocks. The rocks of this group have a characteristic texture and composition. The texture is such that larger crystals of dolomite are scattered in and surrounded by a fine-grained matrix of calcite and clay. The rock consists of substantial amounts of dolomite and calcite in the carbonate portion, with significant amounts of acid-insoluble residue consisting largely of clay. Two reactions have been reported with rocks of this sort, as follows:

(1) Dedolomitization Reaction. It is believed that this reaction produces harmful expansion of concrete (ref 4d). Magnesium hydroxide, or brucite ($Mg(OH)_2$), is formed by this reaction; its presence in concrete that has expanded and that contains carbonate aggregate of the indicated texture and composition is strong evidence that this reaction has taken place.

(2) Rim-Silicification Reaction. This reaction is not definitely known to be damaging to concrete, although there are some data that suggest that a retardation in the rate of strength development in concrete is associated with its occurrence. The reaction is characterized by enrichment of silica in the borders of reacted particles (ref 4e). This is seen as a positive or raised border at the edge of cross sections of reacted particles after they have been etched in dilute hydrochloric acid. Reaction rims may be visible before the concrete surfaces are etched.

Fortunately, carbonate rocks that contain dolomite, calcite, and insoluble material in the proportions that cause either the dedolomitization or rim-silicification reactions are relatively rare in nature as major constituents of the whole product of an aggregate source.

2. CRITERIA FOR RECOGNITION OF POTENTIALLY HARMFUL REACTIVE CARBONATE ROCKS. The criteria for recognizing potentially harmful reactive rocks serve to indicate those dolomitic carbonate rocks capable of producing the dedolomitization or rim-silicification reaction. Since the reactions generated by some very dolomitic or by some nondolomitic carbonate rocks are not known to be harmful to concrete, no attempt is made to provide guides for recognition of these rocks at this time.

a. When petrographic examinations are made according to CRD-C 127 of quarried carbonate rock or of natural gravels containing carbonate-rock particles, adequate data concerning texture, calcite-dolomite ratio, the amount and nature of the acid-insoluble residue, or some combination of these parameters will be obtained in order to recognize potentially reactive rock. Rocks associated with observed expansive dedolomitization have been found to be characterized by fine grain (generally 50 microns or less), with the dolomite largely present as small, nearly euhedral crystals generally scattered in a finer grained matrix in which the calcite is disseminated. The tendency to expand, other things being equal, appears to increase with increasing clay content from about 5 to 25% by weight of the rock, and also appears to increase as the calcite-dolomite ratio of the carbonate portion approaches 1:1.

b. Samples of rock recognized as potentially reactive by petrographic examination will be tested for length change during storage in alkali solution in accordance with CRD-C 146 (ASTM Designation: C 586). Rock characterized by expansion of 0.1% or more by or during 84 days of test by CRD-C 146 shall be classified as potentially reactive.

c. If adequate, reliable data are available to demonstrate that concrete structures containing the same aggregate have exhibited deleterious reactions, the aggregate shall be classified as potentially reactive on the basis of its service record.

3. APPLICATION OF CRITERIA. The application of engineering judgment will be required in making the final decision as to which rocks are to be classified as innocuous and which are to be classified as potentially reactive. Once a rock has been classified as potentially reactive, the action to be taken should be as indicated in the following subparagraphs.

a. Avoid use as aggregate of rock classified as potentially reactive by appropriate procedures such as selective quarrying.

b. If it is not feasible to avoid the use of rock classified as potentially reactive, then specify the use of low-alkali cement, the minimum aggregate size that is economically feasible, and dilution so that the amount of potentially reactive rock does not exceed 20% of the coarse aggregate, or 20% of the fine aggregate, or 15% of the total aggregate in cases where there is a potentially reactive rock in both the coarse and fine aggregates. If the sample is in the form of core, the 20% value shall be invoked on a volume basis; if the sample is a manufactured or natural aggregate, the 15 and 20% values shall be weighted average values as determined by CRD-C 127 (Method of Petrographic Examination of Aggregates for Concrete).

c. If it is not practical to enforce conditions a or b, then the aggregate source that contains potentially reactive rock shall not be indicated as a source from which acceptable aggregate may be produced.

4. LITERATURE REFERENCES. The following references contain descriptions of the various types of alkali-carbonate rock reaction:

a. U. S. Army Engineer Waterways Experiment Station, CE, Aggregate Investigations, Milford Dam, Kansas, Examination of Cores from Concrete Structures, by Katharine Mather, W. I. Luke, and Bryant Mather. Technical Report No. 6-629, June 1963, Vicksburg, Miss.

b. ____________, Investigation of a Reaction Involving Nondolomitic Limestone Aggregate in Concrete, by A. D. Buck. Miscellaneous Paper No. 6-724, June 1965, Vicksburg, Miss.

c. ____________, Results of Laboratory Tests and Examinations of Concrete Cores, Carlyle Reservoir Spillway, Carlyle, Illinois, by W. O. Tynes, W. I. Luke, and B. J. Houston. Miscellaneous Paper No. 6-802, March 1966, Vicksburg, Miss.

d. Hadley, D. W., "Alkali reactivity of carbonate rocks--expansion and dedolomitization." Proceedings, Highway Research Board, vol 40 (1961), pp 462-474.

e. Bisque, R. E., and Lemish, John, "Chemical characteristics of some carbonate aggregate as related to durability of concrete." Highway Research Board Bulletin No. 196 (1958), pp 29-45.

f. National Research Council–Highway Research Board, "Symposium on alkali-carbonate rock reactions." Highway Research Record No. 45 (1964), Washington, D. C.

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13. ABSTRACT Forty-one carbonate rock samples from six quarries in Virginia and Kentucky were tested for potential alkali-carbonate rock reactivity that may take place when certain carbonate rocks are used as aggregates in concrete. Expansion that accompanies this reaction may be deleterious to concrete, so criteria have been established to detect potentially reactive rock (see Appendix A). Petrographic, physical, and chemical data were developed for each sample. In most instances, expansion data were obtained by periodic measurement of length changes of pairs of small rock specimens that were stored in sodium hydroxide solution. Three of the samples were represented by 5 length-change specimens each. Data were examined and compared to determine if criteria for identifying potentially reactive rocks appeared to be effective. In general, but with a few exceptions, the validity of the criteria was confirmed. Failure of criteria to always identify reactive rocks suggests that (a) tests for determining potential reactivity of rock samples containing detectable amounts of dolomite and having an essentially limy mud matrix should include length-change determinations, and (b) length-change determinations should be made on at least two specimens from each sample. These specimens should preferably be from adjacent locations. Length-change data indicated that the material from one of the quarries would not be expected to participate in expansive alkali-carbonate rock reaction. Material from the other five quarries is expected to contain greater or lesser amounts of rock that could participate in this reaction in varying degrees. Based on criteria that have been proposed for application in such cases, and in the absence of service record data on the performance of aggregate from these sources, the quarries are rated as follows: quarry 2, no indication of reactivity; quarry 3, approximately 15% potentially reactive rock; quarry 5, approximately 24% potentially reactive rock; quarry 1, approximately 30% potentially reactive rock; quarry 6, over 50% potentially reactive rock; and quarry 4, approximately 70% potentially reactive rock.

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