DEVELOPMENTS IN SPECIFICATION AND CONTROL

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Alkali-carbonate rock reactions have been regarded as capable of producing damage in concrete. Such damage may be prevented by avoiding the use of reactive rock. Rock may be classed as reactive based on its service record, its behavior in the rock cylinder test (ASTM C 586), or its behavior in concrete test specimens. Alternatively it has been suggested that damage may be prevented, as in alkali-silica reaction, by using low-alkali cement or a pozzolan or both. A supply of reactive rock may be rendered harmless by being diluted with nonreactive rock, or a source of rock may be rendered satisfactory by selective quarrying to discard reactive rock. Construction practices such as vapor barriers below pavements and more closely spaced expansion joints may assist in controlling the effects. Procedures used by the Corps of Engineers to detect reactive carbonate rock are cited and the measures to be taken are quoted.

•AT the 43rd Annual Meeting of the Highway Research Board in 1964, a symposium on alkali-carbonate rock reactions was held that was the basis of Highway Research Record 45, which contained 15 reports and a bibliography. The bibliography listed 56 items. Insofar as these dealt with specifications and control, they generally implied that aggregates of the sort that participated in the detrimental alkali-carbonate rock reaction should not be used. Presumably such exclusion would be based on service record if standard acceptance tests failed to yield a basis for rejection when results of such tests were compared with criteria such as those given in ASTM C 33. Indeed, the early work of Swenson (5) on the rock from Kingston was presented primarily in terms of the fact that the rock had, by service record, been shown to be associated with detrimental expansion of concrete but would not be detected and classed as unacceptable by then-current ASTM criteria. The work of Lemish and associates (2) in Iowa, beginning in 1957, was largely associated with explaining the unsatisfactory service of concrete made using certain sources of carbonate rock aggregates.

Swenson and Gillott (6) reported that the use of a cement of sufficiently low alkali content appeared to have provided a satisfactory solution in the Kingston area. Hadley (1) proposed the dedolomitization reaction and petrographic criteria for the recognition of types of rock that were capable of participation therein.

Newlon and Sherwood (3) reported results of a survey throughout Virginia in which rock from 7 quarries was found to expand more than 0.2 percent in the rock prism test.

This essentially was the state of the art with regard to specification and control in 1963 before the symposium.

In Highway Research Record 45, we find Hadley writing, "Simple test methods have been developed which permit rapid identification of expanding rocks and indicate their general level of reactivity." Swenson and Gillott, under the heading "Recommended Field Practice", reiterated that expansion will be reduced to "safe" values if the alkali content of the cement is held to 0.45 or less Na_2O equivalent. They also suggest dilution, attention to joints, and other details. Lemish and Moore indicated progress in detecting the features of rocks that are associated with poor service. Axon and Lind

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pointed out difficulties in correlating petrographic and performance data and report that rock from one quarry was not approved because the concrete showed excessive expansion but none had yet been rejected because of expansion in the prism test. Smith (4), in presenting the results of his experience, noted that necessary precautions included (a) selective quarrying and removal of unacceptable material based on service records and tests to an age of 84 days with an expansion of 0.05 percent or more in a concrete prism made using a cement with more than 1.1 percent alkalies; (b) a vapor barrier installed below the pavement; and (c) expansion joints provided to a greater extent than normally done. Newlon and Sherwood suggested dilution and reduction of cement alkalies to 0.40 percent maximum in some cases. They proposed an expansion in concrete of 0.03 percentage points above the control as indicative of reactive aggregate.

Since 1964 there has been considerable progress in various agencies.

In ASTM Committee C-9, the rock prism test has been standardized and published as Designation C 586-66T. This says, with a variety of qualifying comments, that a rock prism that expands more than 0.10 percent is reactive rock. A letter ballot was canvassed in January 1969 on advancing this method to standard (now C 586-69, effective October 1969).

At the meeting of Subcommittee II-b of Committee C-9 in December 1968, there was discussion of publication of the results of a cooperative study of the use of the mortar-bar test (C 227) on reactive carbonate aggregates. References are now included in C 227 regarding the lower level of expansion found when this test is used on reactive carbonate rocks as contrasted with the higher levels obtained when used with an equally reactive siliceous rock.

In December 1968, Committee C-9 accepted, subject to letter ballot, a revision of the specifications for concrete aggregate (C 33) setting, for the first time, criteria on reactive carbonate rocks in the ASTM aggregate specifications. This, in effect, says a reactive carbonate rock is one that shows 0.1 percent or more expansion in 84 days or less. Since this proposal was not approved on the letter ballot, additional consideration was given to the matter. In ASTM Designation C 33-71a, effective September 1971, the topic is covered in paragraph A1.1.5, which does not include the target value previously considered, as follows:

> A1.1.5 Potential Reactivity of Carbonate Aggregates—The reaction of the dolomite in certain carbonate rocks with alkalies in portland cement paste has been found to be associated with deleterious expansion of concrete containing such rocks as coarse aggregate. Carbonate rocks capable of such reaction possess a characteristic texture and composition. The characteristic texture is that in which large crystals of dolomite are scattered in a fine-grained matrix of calcite and clay. The characteristic composition is that in which the carbonate portion consists of substantial amounts of both dolomite and calcite, and the acid-insoluble residue contains a significant amount of clay. Except in certain areas, such rocks are of relatively infrequent occurrence and seldom make up a significant proportion of the material present in a deposit of rock being considered for use in making aggregate for concrete. ASTM Method C 586, Test for Potential Reactivity of Carbonate Rocks for Concrete Aggregates (Rock Cylinder Method), has been successfully used in (1) research and (2) preliminary screening of aggregate sources to indicate the presence of material with a potential for deleterious expansions when used in concrete.

Meanwhile, in the Corps of Engineers, steps were being taken to revise Appendix II, "Evaluating Reactive Aggregates", in Engineer Manual 1110-2-2000, "Standard Practice for Concrete". This appendix, as adopted in 1965, covered only materials capable of participation in the alkali-silica reaction. The revisions were begun in 1967 and modified in draft in 1968, and the manual as published in November 1971 covered these materials in its Appendix C. Because this document has not been widely circulated, Appendix C is given as an appendix to this paper.

Following the development of the criteria given in Appendix C, the selection of which was based primarily on published work done elsewhere than in the Corps of Engineers, the Waterways Experiment Station undertook an investigation having as its purpose the development of data that would verify or permit modification or refinement of the criteria for permissible expansion, time, and dilution. This program is still in progress.

(Because this manuscript was prepared in 1968 for presentation at the 1969 Annual Meeting of the Highway Research Board, no attempt is made to include developments since 1968 except as they directly concern documents referenced then. Consequently, no summary or conclusion is regarded as appropriate now; none was included in the 1968 version.)

REFERENCES

1. Hadley, David W. Alkali Reactivity of Dolomitic Carbonate Rocks. Highway Research Record 45, 1964, pp. 1-20.
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3. Newlon, H. H., Jr., and Sherwood, W. C. Initial Investigations. Progress Report 1, Potentially Reactive Carbonate Rocks. Virginia Highway Research Council, 1962.
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5. Swenson, E. G. A Canadian Reactive Aggregate Undetected by ASTM Tests. ASTM Bull. 226, 1957, pp. 48-50.
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APPENDIX

ALKALI-CARBONATE ROCK REACTION

1. General Statement. The results of studies that have been reported indicate that four types of alkali-carbonate rock reaction may be recognized in concrete. A thorough review of research through 1964 is contained in reference 4f below. 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 four types of reactions are discussed below:

a. Reactions Involving Nondolomitic Carbonate Rocks. Some rocks which contain little or no dolomite may be reactive [ref. 4a, b below]. The reaction is characterized by reaction rims which 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; that is, 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 below]. 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 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. This reaction is believed to have produced harmful expansion of concrete [ref. 4d below]. Magnesium hydroxide, brucite ($Mg(OH)_2$),

is formed by this reaction; its presence in concrete which has expanded and which 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 which 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 below]. 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 Harmfully Reactive Carbonate Rocks. These criteria 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 size (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 expansion, 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 or fine aggregate or 15% of the total if reactive material is present in both.

c. If it is not practical to enforce conditions a or b, then the aggregate source which 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. Technical Report No. 6-629, Vicksburg, Miss., June 1963.

b. U. S. Army Engineer Waterways Experiment Station, CE, Investigation of a Reaction Involving Nondolomitic Limestone Aggregate in Concrete, by Alan D. Buck, Miscellaneous Paper No. 6-724, Vicksburg, Miss., June 1965.

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e. Bisque, R. E., and Lemish, John, "Chemical Characteristics of Some Carbonate Aggregate as Related to Durability of Concrete." Highway Research Board Bull. 196, Washington, D. C. (1958), pp 29-45.

f. Highway Research Board, "Symposium on Alkali-Carbonate Rock Reactions." Highway Research Record No. 45, HRB Publication 1167 (1964), 244 pp.