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Introduction

As a result of his well-known studies, Thomas E.. Stanton, formerly Materials and Research Engineer of the California Division of Highways, concluded that if Portland cement did not contain in excess of 0.60 percent alkalies (Na2O equivalent) no detrimental expansion would result in concrete containing reactive aggregates.

Stanton's conclusion has been accepted by a large number of engineers and scientists but others have contended that a limitation on the maximum percentage of alkalies in cement will not of itself positively control adverse reactions. The latter group believes that additional safeguards are necessary to assure satisfactory performance.

The purpose of this report is not to comment on the respective merits of these viewpoints or to discuss the theoretical aspects but to present the service record of a considerable group of structures and pavements in which low-alkali cements and reactive aggregates have been used.

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STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

A report on

SERVICE RECORD OF CONCRETE CONTAINING REACTIVE AGGREGATES AND LOW-ALKALI CEMENT

55-03

State of California
Department of Public Works
DIVISION OF HIGHWAYS
- - - - - - -
Materials and Research Department

December 20, 1955

District V General
Lab W.O. 5001-R-54

Mr. G. T. McCoy
State Highway Engineer
Sacramento
California

Dear Sir:

Submitted for your consideration is:

A report on

SERVICE RECORD OF CONCRETE CONTAINING

REACTIVE AGGREGATES AND LOW-ALKALI CEMENT

Study made . . . . Technical Section
Under general direction of . . . . . . Bailey Tremper
Report prepared by . . . . Bailey Tremper and
L. P. Kovanda

Yours very truly

F. N. Hveem
F. N. Hveem
Materials and Research Engineer

cc:E.Withycombe
FWPanhorst
JCYoung

SERVICE RECORD OF CONCRETE CONTAINING REACTIVE AGGREGATES AND LOW-ALKALI CEMENT

INTRODUCTION

As a result of his well-known studies, Thomas E. Stanton, formerly Materials and Research Engineer of the California Division of Highways, concluded that if portland cement did not contain in excess of 0.60 percent alkalies (Na_2O equivalent) no detrimental expansion would result in concrete containing reactive aggregates.

Stanton's conclusion has been accepted by a large number of engineers and scientists but others have contended that a limitation on the maximum percentage of alkalies in cement will not of itself positively control adverse reactions. The latter group believes that additional safeguards are necessary to assure satisfactory performance.

The purpose of this report is not to comment on the respective merits of these viewpoints or to discuss the theoretical aspects but to present the service record of a considerable group of structures and pavements in which low-alkali cements* and reactive aggregates have been used.

HISTORY

Starting about 1940 the California Division of Highways has accepted concrete aggregates that were considered to be reactive provided the portland cement used with them did not contain more than 0.60 percent of alkalies (Na_2O equivalent). Field inspections have been made from time to time to determine if there was evidence that the

*In this report low-alkali cements are defined as those containing not more than 0.60 percent of alkalies calculated as $Na_2O + 0.658\ K_2O$.

use of reactive aggregate-low alkali cement combinations were showing evidence of detrimental reaction. No evidence of such distress has been observed. These examinations were confined largely to bridges constructed in the early forties and to older structures containing reactive aggregates and cements that were from sources that have been characteristically low in alkalies but which were not positively identified as such by direct chemical analysis.

A similar inspection was proposed for 1955 but it was decided to select one highway district and to inspect all known minor structures as well as bridges and pavements in the district. District V, along the southwestern coast of California, comprising the counties of San Benito, Monterey, San Luis Obispo and Santa Barbara, was selected for this inspection. This district was chosen because nearly all of the available aggregates are considered to be reactive due to the widespread presence of opaline shales and cherts in critical amounts. It was this type of aggregate that led Stanton to the discovery of the alkali-aggregate reaction. Opaline minerals from this area have been used extensively by many investigators in the laboratory study of the alkali-aggregate reaction. Furthermore a great many of the early pavements and structures described by Stanton as seriously cracked due to the use of reactive aggregates and, presumably, high alkali cement were obtained from the same sources that were involved in the present investigation.

The year 1940 was taken as a starting point because it marks approximately the time at which a conscious effort was made through specifications to require that low-alkali cement be used whenever reactive aggregates were known to be involved. It was decided to include construction through the year 1954 in order to obtain a complete record but it is realized that some of the more recently constructed projects are not necessarily conclusive as the alkali-aggregate reaction may not become apparent in as short a time as one year.

INSPECTION RESULTS

Table I lists the projects that were inspected. In no case did the observer find visual evidence which in his opinion was indicative of cracking or other distress due to the alkali-aggregate reaction. The inspections were made by L. P. Kovanda, recently retired as Associate Materials and Research Engineer. He inspected pavements and structures contained in a list which included all concrete construction performed by contract in District V during the years 1940-1954 inclusive. His report contains the following statements:

> "No evidence of cement-aggregate reaction was found in any of the concrete structures which were inspected and which had been completed subsequent to 1940.
>
> "The only other conditions of the concrete in the structures which were of interest were observed at Bridge No. 51-15, V-S.B-2-D which contained a shrinkage or settlement crack in the east arch face, Bridge No. 51-172R, V-S.B-2-E, the entrance of the Gaviota Tunnel shows shrinkage and possible settlement cracks and at Bridge No. 51-91, V-S.B-56-A, the curbs, railing and posts show bad spalling of concrete over the steel reinforcement due to thin coverage of rusting steel by apparently porous concrete."

The concrete inspected includes 42 bridges, 2 pavements, 1 tunnel and 20 projects containing 56 minor structures such as box culverts, cattle passes, headwalls, curbs, etc. Twenty-four (24) bridges, one pavement and about two-thirds of the minor structures are more than 5 years old. Actually all of the projects except one were located in San Luis Obispo and Santa Barbara counties.

The data in Table I shows that the fine aggregate used throughout came from five sources as follows:

1. Sisquoc
2. Atascadero
3. Saticoy
4. Montalvo
5. San Gabriel

The San Gabriel sand was used on one project only and it is the only one that is considered to be non-reactive. Of the remaining four, the Atascadero sand was at one time considered to be non-reactive and it will be noted that it was used with high-alkali cement in 1951 in two bridges constructed under Contract 1-5VC35-F. More recent tests have shown that certain portions of the deposit may produce reactive aggregates.

It will be noted in Table I that the coarse aggregate in many cases came from sources other than that from which the sand was obtained. The coarse aggregate from Piru and those from the reactive sand sources listed above are considered to be reactive. The remaining coarse aggregates are considered to be non-reactive.

The criterion used in characterizing the aggregates as reactive or non-reactive is the result of the mortar bar expansion test. If when tested with a cement containing 1.00 percent or more of alkalies in accordance with the Tentative Method of Test for Potential Alkali Reactivity of Cement-Aggregate Combinations, ASTM Designation: D 227-50T (the so-called dry-mix) the expansion after 1 year exceeded 0.10 percent or when tested in accordance with ASTM Designation: C 227-52T (the so-called wet mix) expansion after 6 months exceeded 0.10 percent, the aggregate was considered to be reactive. When the expansion at these periods was less than 0.10 percent the aggregate was considered to be non-reactive. Table II gives typical results of the fine aggregates involved. It will be noted that those considered to be reactive gave expansions well in excess of the limiting value. Test results of the coarse aggregates are not available but definite data on their reactivity is not of importance in this study because the sands alone are capable of developing harmful reaction if used with high-alkali cements.

The cement used came from seven mills and with the exception of that furnished on contracts 1-5VC35-F and 51-5VC9-F were certified by the manufacturer to contain not more than 0.60 percent alkalies. The last column of Table I lists the average results of alkali determinations made in the laboratory of the California Department of Highways on samples taken at the time of delivery to the work. With the exception of the cements furnished on contract 1-5VC35-F which was not specified to be low-alkali there were two projects in which the alkali content was found to be in excess of 0.60%. In one case the result was 0.61 percent and in the other 0.67 percent. For the remainder it will be noted that the alkali content varied from 0.21 percent to 0.58 percent but that the majority was in the range of 0.50 to 0.58 percent. For the concrete included in this investigation a maximum limitation of 0.60 percent alkalies has been as effective to date in preventing harmful reactions as would a lower maximum.

The minor structures inspected in this investigation were 56 in number. While possibly of less importance from the standpoint of volume of concrete, they are nevertheless of considerable importance from the standpoint of the objectives of this investigation because they are so located as to be subjected to a relatively high level of moisture.

SUMMARY

The inspection of 42 concrete bridges, 2 pavements, 1 tunnel and 56 minor structures constructed during the period 1940 to 1954 showed no evidence of harmful alkali-aggregate reaction. On all projects but one the fine aggregate used was highly reactive as shown by the mortar bar expansion test. With a few exceptions the portland cement used in the concrete contained less than 0.60 percent alkalies (Na_2O equivalent). Experience has shown that most of the aggregates involved when used with high-alkali cement have produced unsatisfactory concrete characterized by a pattern of wide open cracks and other evidence of alkali-aggregate reaction. The restriction of alkalies in the cement to a maximum of 0.60 percent (Na_2O equivalent) has been found to be fully effective thus far in controlling the alkali aggregate reaction.

TABLE I

LIST OF STRUCTURES AND PAVEMENTS IN DISTRICT V
INSPECTED SEPTEMBER-OCTOBER, 1955
(Arranged by year of construction)

Date Const.	Co., Rte., Sec.	Contract Number	Description	Coarse Aggregate	Fine Aggregate	Portland Cement	
						Brand	% Alkalies
1940	S.B-2-D	0-5VC5	Small Structure	Irwindale	Sisquoc	A	(1)
1940	S.B-2-D	25VC1	Small Structure	Irwindale	Sisquoc	A	(1)
1941	Mon-2-I	214TC3	Bridge 44-11	Atascadero-Oro Fino	Atascadero	A	(1)
1941	SLO-2-E	214VC1-P	Bridge 49-14R	Atascadero	Sisquoc	B	(1)
1941	SLO-33-B	214XLC8	Bridge 49-28	Lindsay-Atascadero	Lindsay-Atascadero	B	(1)
1941	SLO-33-B	214XC22	Bridge 49-29	Atascadero	Atascadero-Sisquoc	C	(1)
1941	SLO-58-A	414XLC1-P	Bridge 49-91	Atascadero	Sisquoc	B	(1)
1941	S.B-2-P,Q	5VC8-F	Small Structure	Irwindale	Saticoy	D	0.51
1941	S.B-2-G	214VC2-P	Bridge 51-33	Saticoy	Saticoy	B	(1)
1941	S.B-2-F	25VC4	Bridge 51-30	Irwindale	Saticoy	B	(1)
1942	S.B-2-G	25VC2	Small Structure	Montalvo-Saticoy	Montalvo-Saticoy	D	(1)
1942	S.B-2-F	25VC4	" "	Same	Same	E	(1)
1946	S.B-2-Q,G	5VC5	Bridge 51-162	Irwindale-Roscoe	Saticoy-Roscoe	F	0.55
1946	S.B-2-Q,G	5VC5	Bridge 51-163	Same	Same	F	0.55
1946	S.B-2-Q,G	5VC5	Bridge 51-167	Same	Same	F	0.55
1946	S.B-2-Q,G	5VC5	Bridge 51-168	Same	Same	F	0.55
1946	S.B-2-Q,G	5VC5	Bridge 51-169	Same	Same	F	0.55
1946	S.B-2-Q,G	5VC5	Bridge 51-171	Same	Same	F	0.55
1947	S.B-2-Q	5VC6-F	Small Structure	Irwindale	Saticoy	F	0.42
1947	S.B-2-G	5VC9-F	Small Structure	Same	Same	D	0.49

Table I(Con't.)

Date Const.	Co., Rte., Sec.	Contract Number	Description	Coarse Aggregate	Fine Aggregate	Portland Cement Brand	Portland Cement % Alkalies
1948	SLO-2-E	5VC19-F	Bridge 49-14L	Granite	Sisquoc	G	(2)
1948	SLO-2-E	5VC19-F	Small Structure	Granite	Sisquoc	G	(2)
1948	SLO-33-E	014VC52	Bridge 49-86	Atascadero	Atascadero	G	0.28
1948	S.B-2-S.B	5VC12-F	Bridges 51-13R,L	Irwindale	Saticoy	D	0.54
1948	S.B-2-S.B	5VC12-F	Pavement	Irwindale	Saticoy	D	0.54
1948	S.B-2-S.B	5VC12-F	Small Structure	Irwindale	Saticoy	D	0.54
1948	S.B-2-G,F	05VC3	Small Structure	Piru	Saticoy	(D (E	(2)
1948	S.B-2-D	14VC36-FP	Bridges 51-3, 51-17	Irwindale	Sisquoc	F	(2)
1948	S.B-2-D	05VC18-F	Bridge 51-15	Irwindale	Sisquoc	F	0.54
1948	S.B-2-D	05VC18-F	Small Structure	Irwindale	Sisquoc	F	0.54
1949	S.B-2-J	05VC24	Bridges 51-53S, 51-47	Irwindale	Saticoy	D	0.50
1949	S.B-2-J	05VC24	Bridges 51-133S,L	Irwindale	Saticoy	D	0.50
1949	S.B-56-A	014KC29	Bridge 51-89	Irwindale	Sisquoc	F	0.55
1949	S.B-56-E	5DVC1-P	Small Structure	Granite	Sisquoc	G	0.36
1951	SLO-2-B	1-5VC35-F	Bridges 49-2L, 49-3L	Atascadero	Atascadero	A	1.16
1951	SLO-56-C	1-14VC100	Bridge 49-72	Atascadero	Atascadero	B	0.61
1951	S.B-2-D,E	1-5VC36	Small Structure	Sisquoc	Sisquoc	G	0.21
1951	S.B-80-B	51-5VC4-Y	Small Structure	Sisquoc	Sisquoc	G	0.32
1951	S.B-80-B	51-5VC8-Y	Small Structure	Sisquoc	Sisquoc	G	0.28
1951	S.B-56-A	51-5VC10-F	Bridge 51-173	Sisquoc-Granite	Sisquoc	B	0.47
1951	S.B-56-A,B	51-5VC9-F	Small Structure	San Gabriel	San Gabriel	B	0.54
1952	S.B-2-J	52-5VC5-F	Bridges 51-49-L, 51-49R, S	Saticoy	Saticoy	B	0.54
1952	S.B-2-J	52-5VC5-F	Bridge 51-174	Saticoy	Saticoy	B	0.54
1952	S.B-2-J	52-5VC5-F	Briage 51-54R	Saticoy	Saticoy	B	0.54

Date Const.	Co., Rte., Sec.	Contract Number	Description	Coarse Aggregate	Fine Aggregate	Portland Cement Brand	Portland Cement % Alkalies
1952	S.B-2-E	51-5VC10-F	Small Structure	Sisquoc-Granite	Sisquoc	-(B (G	0.48
1952	S.B-149-A	52-5VC8	Small Structure	San Gabriel	Sisquoc	-(B (F	0.55
1953	S.B-2-E	52-5VC3	Tunnel 51-172R	Irwindale	Sisquoc	-(B (G	0.54
1954	S.B-2-H,J	54-5VC2-F	Small Structure	Montalvo	Montalvo	G	0.25
1954	S.B-2-H,J	54-5VC2-F	Bridges 51-178 51-50RL	Montalvo	Montalvo	G	0.25
1954	S.B-2-H,J	55-5VC4-F	Pavement	Saticoy	Saticoy	B	0.58
1954	S.B-2-H,J	55-5VC4-F	Small Structure	Saticoy	Saticoy	B	0.67
1954	S.B-2-H,J	55-5VC4-F	Bridges 51-51R,L	Saticoy	Saticoy	B	0.58
1954	S.B-2-H,J	55-5VC4-F	Bridges 51-52R,L 51-175	Saticoy	Saticoy	B	0.58
1954	S.B-2-H,J	55-5VC4-F	Bridge 51-177	Saticoy	Saticoy	B	0.58

Notes: Values for % alkalies shown in last column are averages of determinations made in laboratory of California Division of Highways on samples received from work. (Expressed as Na_2O equiv.)

(1) Test records not found. Certified by manufacturer to be low-alkali.

(2) Test records destroyed in fire. Certified by manufacturer to be low-alkali.

TABLE II

EXPANSION OF MORTAR CONTAINING SANDS AND HIGH-ALKALI CEMENT

Source of Sand	Expansion in Percent	
	C 227-50T 12 Months	C 227-52T 6 Months
Sisquoc	0.18	0.19
Saticoy	0.65	0.61
Montalvo	0.37	----
Atascadero*	----	0.08
San Gabriel	0.02	0.02

*Expansion at 3 months was 0.06 percent. In tests now under way certain combinations of sand and crushed coarse aggregate have developed expansions greater than 0.10 percent in less than 6 months.