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State of California
Department of Public Works
Division of Highways

MATERIALS AND RESEARCH DEPARTMENT

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December 30, 1960

# ALKALI-AGGREGATE REACTION WITH LOW-ALKALI CEMENT

In 1958, engineers of the Bridge Maintenance Department reported evidence of distress from alkali-aggregate reaction in six bridges on the route of U.S. No. 395, north and south of Bishop. The area lies east of the Sierra Nevada range and west of the Nevada state line.

Three of the bridges constructed at an unknown date were widened in 1953. The source of materials used in the original construction is not known. This concrete shows no distress. On the contrary, the new construction does show distress as will be discussed later.

One new bridge was constructed in 1949 and two in 1953. The concrete in these structures shows distress.

The distress in the above six structures consists of cracking ranging from a well defined pattern of open cracks to fine cracks suggestive of advanced crazing due to shrinkage on drying.

The aggregates in all of the new construction were obtained from a sand and gravel pit in Bishop. The aggregates were considered to be reactive and low-alkali cement ($Na_2O$ equivalent not in excess of 0.60 percent) was specified and was so certified by the mills supplying it. Check tests made of cement shipments to other work during the periods of construction indicate that the alkali content of the cements furnished was in the range of 0.55 to 0.60 percent $Na_2O$ equivalent.

Investigation developed the fact that none of the concrete was air-entrained. Winters are severe in this area and this raised the possibility that the distress might be due in part or in whole to damage from freezing and thawing.

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The area is arid and this fact probably accounts for the fact that pronounced distress was not noted, or not reported, until 5 years after construction.

Dr. L. S. Brown, Senior Research Petrographer, Portland Cement Association, inspected these structures in the fall of 1958. He reported as follows:

> "The observed pattern of cracking, variously developed or manifested, is similar to that we come to associate with alkali-reaction, or consider distinctive of alkali-aggregate reaction."

Dr. Brown suggested that cores from the structures be sent to him for petrographic examination.

In the fall of 1959, a total of 15 cores was obtained from the structures. These included a few from the old construction in the bridges that were widened subsequently and also from a seventh bridge which shows no signs of distress. The latter bridge was constructed with aggregates from a source known as the Adams pit. The cement was not specified to be low in alkali but it was supplied by a mill from which the alkalies rarely exceed 0.60 percent.

Upon receipt of the cores in the laboratory, they were stored in the fog room for 10 days. At this time, all of the cores containing the Bishop aggregates had exuded a syrupy liquid and one pop-out was observed. The cores containing aggregates from the other sources did not develop exudations. It was noted that the aggregate in the cores from the original construction of the three bridges that were subsequently widened was of an entirely different character than that of the Bishop or Adams aggregates.

Each of the cores was sawed in two longitudinally, and one half was shipped to the Portland Cement Association laboratory in Skokie, Illinois. Because of the recent retirement of Dr. Brown, the PCA laboratory has been unable to date to examine the cores.

Early in 1960, Dr. Richard C. Mielenz became aware of the condition of these bridges and offered to examine specimens from the cores. A portion of a core, No. EU-7B, containing Bishop aggregates and also one from a core, No. EU-9B, containing the unknown aggregate from original construction, was sent to him. On May 18, 1960, Dr. Mielenz reported as

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follows:

> "Core EU-9B includes a crushed granodiorite coarse aggregate and a natural sand composed essentially of granitic rocks, quartz and feldspars. No evidence of alkali-aggregate reaction was discerned.
>
> "Core No.EU-7B exhibits all of the classical evidence of severe alkali-aggregate reaction. The aggregate is a natural gravel and sand of complex lithology. The deleteriously alkali-reactive particles are rhyolites. The reacting particles display reaction rims and peripheral deposits of alkali silica gel, which also penetrates microfractures and air voids. The gel has exuded onto the sawed surface of the core. The air voids also include meager deposits of the high-sulfate form of calcium sulfoaluminate."

At the time the cores were obtained, samples of aggregates from the Bishop and Adams pit were taken for laboratory testing. The sands were prepared in gradings meeting the requirements of our specifications. Bars were prepared for test according to ASTM Designation: C 227-58T. Four test cements were prepared having alkalies as $Na_2O$ equivalent in the range of 0.20 to 0.70 percent. The test cements were made by blending two cements.

The maximum expansion of any of the cements with the Adams sand up to the age of 1 year is 0.017 percent. The effect of alkali content on expansion of the Bishop sand is pronounced and is shown graphically in Figure 1. The results indicate that an alkali content of less than 0.35 percent is necessary to meet the criteria given in ASTM Designation: C 33-57.

Gravel from Bishop contained particles up to 1-1/2 inch in size. It was crushed to pass 3/4-inch. It was combined with the Bishop sand to produce a grading complying with our specifications. A single batch of concrete with each of the test cements was mixed to give 6 sacks of cement per cubic yard and a slump of 4 $\pm$ 1/2-inch. Four 3 x 3 x 10-inch gage length bars were molded from each batch. These were stored in sealed containers at 100 F in the same manner as prescribed in ASTM Designation: C 228-58T. Length changes have been measured periodically up to 1 year.

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The results are shown in Figure 1.

The expansion of the concrete bars was less than that of the mortar bars. Presumably, had a higher cement factor been used in the concrete, the expansions would have been greater. The order of performance of the cements in the concrete bars was the same as in the mortar bars. With 0.50 percent alkalies, the concrete bars expanded more than 0.05 percent at 3 months and more than 0.10 percent at 6 months. The expansion with 0.35 percent alkalies was less than these values. In contrast the sand mortar bars with 0.35 percent alkalies exceeded the limit at 6 months.

The results suggest the desirability of studying the procedure of C 228-58T which now provides for crushing coarse aggregate to sand sizes with a possibility of providing for testing the coarse aggregate and sand together in bars of suitable size.

The evidence seems conclusive that the Bishop aggregates have reacted deleteriously when used with cement containing alkalies slightly less than 0.60 percent. Laboratory tests indicate that the maximum safe content of alkalies ($Na_2O$ equivalent) that can be used with these aggregates is about 0.30 percent.

Reference is made to a report of the Materials and Research Department, "Service Record of Concrete Containing Reactive Aggregates and Low Alkali Cement" dated December 20, 1955. The condition of all state highway structures in three counties in which the aggregates are predominantly reactive, was reported to be good when used with cements containing less than 0.60 percent alkalies. In many cases, the alkali contents were in excess of 0.55 percent. The age of the concrete at the time of inspection was from 1 to 15 years.

The Bishop aggregates furnish the only known example in California Division of Highways' experience of detrimental reaction when used with cements approaching, but not exceeding, 0.60 percent alkali content.

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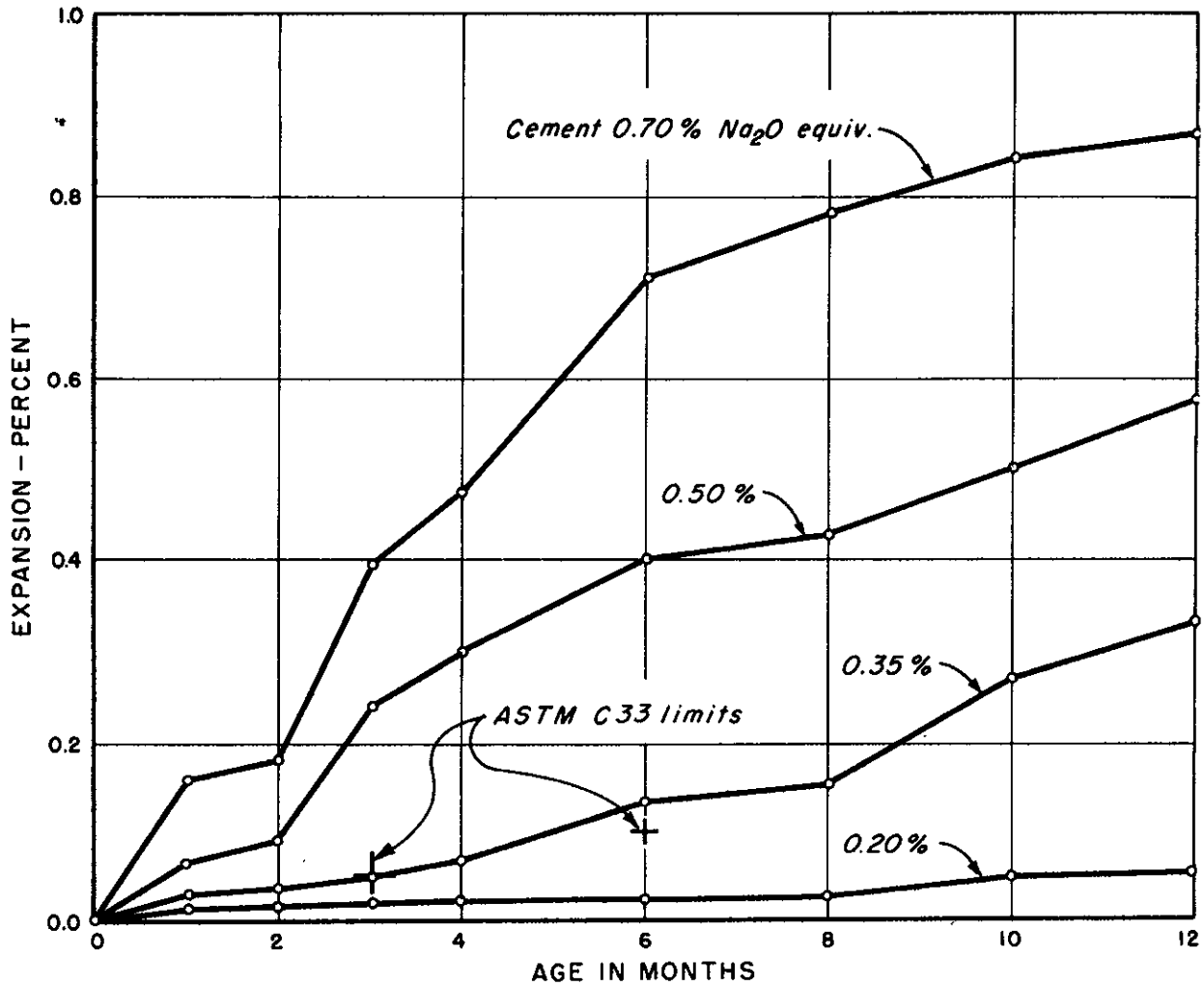
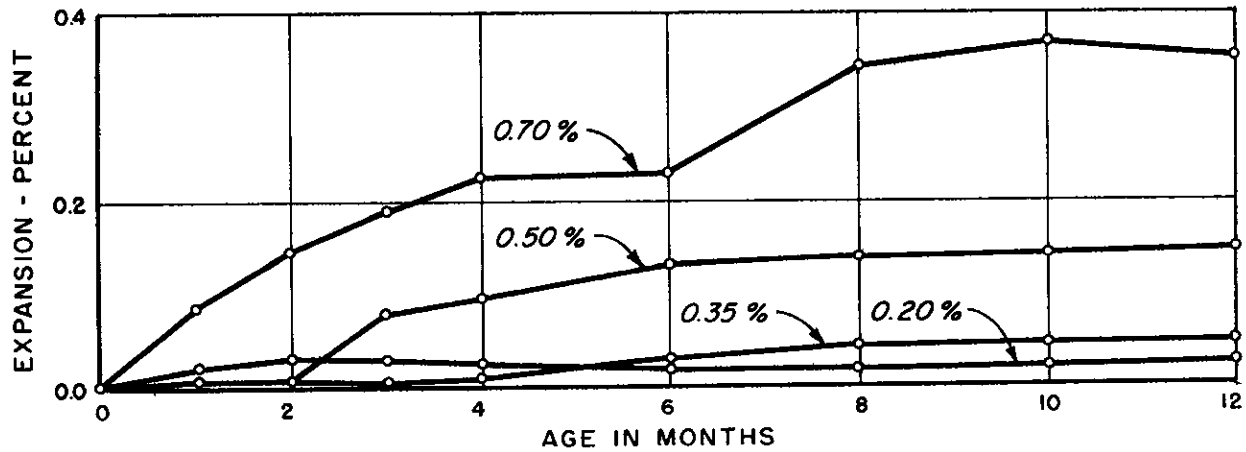
Figure 1




Bishop Sand - ASTM C 227 - 58T




3"x 3"x 11 ¼" Bars Bishop Sand and Gravel 6 Sack Concrete
¾" Max. size aggregate stored in sealed containers at 100°F

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