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ALKALI-SILICA REACTION IN CONCRETE FROM THE NEW SAVANNAH BLUFF LOCK AND DAM, GEORGIA-SOUTH CAROLINA

by

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Final Report

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Prepared for U. S. Army Engineer District, Savannah
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The New Savannah Bluff Lock and Dam was built in 1937. The concrete now shows substantial cracking. Tests were conducted to determine if alkali-silica reaction has occurred. Some calcium sulfoaluminate was seen in cracks and on broken core surfaces, but the amount appeared to be normal. Although the concrete was not air-entrained, its appearance and physical condition did not indicate that any significant frost damage had occurred. It is believed that much or all of the cracking seen in this structure is due to the alkali-silica reaction.

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Preface

The work described in this report was done for the U. S. Army Engineer District, Savannah. The District kindly gave permission to publish the work in the interest of disseminating technical knowledge in cement-aggregate reactions.

Funds for preparing this edition were provided by the Concrete Technology Information Analysis Center (CTIAC). This is CTIAC report No. 33.

Colonel John L. Cannon, CE, was Commander and Director of the U. S. Army Engineer Waterways Experiment Station when this work was done. Mr. F. R. Brown was Technical Director.

Contents

Conversion Factors, U. S. Customary to Metric (SI) Units of Measurement

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
inches	25.4	millimetres
pounds (force) per square inch	6894.757	pascals

Corps of Engineers, USAE Waterways Experiment Station	Concrete Report	Concrete Laboratory P. O. Box 631 Vicksburg, Mississippi
Project Tests of Cores from New Savannah Bluff Lock and Dam		Date 18 October 1977 ADB

Background

1. The New Savannah Bluff Lock and Dam was built in 1937. The concrete now shows substantial cracking.[1] The work described in this report was done to determine if alkali-silica reaction has occurred. An earlier investigation in 1973 by the US Army Engineer Division Laboratory, South Atlantic (SADL), had concluded that there was no alkali-silica reaction.[1] However, since then other work has documented alkali-silica reaction involving the same or a similar granite gneiss coarse aggregate.[2] That report[2] showed that some granite gneiss was alkali-silica reactive in some conditions and that the presence of alkali-silica reaction gel could vary in abundance with the concrete and the environment.

Samples

2. Nine concrete cores were received on 24 August 1977 from the US Army Engineer District, Savannah, for examination and testing. They are described below:

Concrete Laboratory Serial No. SAV-4 CON-	Field Data
1	Core 9, Sta 0+76.4B
2	Core 10, Sta 1+29.7B
3	Core 11, Sta 1+87B
4	Core 12, Sta 3+43.6B
5	Core 13, Sta 3+44.6B
6	Core 14, Sta 4+25.1B

All of the cores listed above were 4-in. diameter vertical cores taken from the land wall of the lock on the Georgia side. Cores 9, 10, 11, and 14 correspond closely to locations of cores 7, 3, 8, and 2 tested by SADL in 1973.[1] Cores 12 and 13 are from new locations.

Concrete Laboratory Serial No. SAV-4 CON-	Field Data
7	Core 15. Horizontal NX core 3.8 ft upstream from door; 3.3 ft up wall under catwalk.
8	Core 16. Horizontal NX core. Located between 15 and 17.
9	Core 17. Vertical NX core. 32.5 ft downstream of door; in from wall 4.1 ft.

The three NX cores came from the dam pier on the South Carolina side. They correspond closely to locations of cores 4, 5, and 6 tested by SADL in 1973.[1] None of the cores were wrapped to preserve field moisture conditions.

Test procedure

3. The cores were inspected. Petrographic samples were selected from cores 9 and 11. Other portions of cores were selected for ultrasonic pulse velocity measurements, compressive strength tests, and length-change tests. The length-change specimens from cores 9 and 14 were soaked in water overnight and then measured to obtain a reference length; the specimen from core 11 was soaked in water for 6 days with periodic measurements to determine if additional soaking had an appreciable effect on the specimen. The additional soaking did not have an appreciable effect. The reading after 6 days of soaking was used as the reference length of the specimen from core 11. Once reference lengths were established, the three specimens were stored at 100 percent relative humidity and 100°F with periodic length measurements made after the specimens had cooled to room temperature before each reading.

4. Broken core ends and some core surfaces were examined with a stereomicroscope for evidence of alkali-silica reaction. In addition, the petrographic samples from cores 9 and 11 were sawed along the axis of the cores. A sawed surface from each of the two pieces was then ground to provide a smooth matte surface which was examined with a stereomicroscope for signs of alkali-silica reaction. This included observation to determine if the aggregate particles were cracked and if they showed reaction rims.

5. Photographs were taken of a sawed and polished surface of the petrographic sample from core 11. These photographs were taken to show evidence of alkali-silica reaction as reaction rims around some of the granite gneiss particles.

6. Two thin sections were prepared from core 11 and were examined with a polarizing microscope.

7. A small amount of alkali-silica gel was obtained from several voids in core 11. Some of this gel was examined as powder immersion mounts with a polarizing microscope. The rest of it was ground in water; this slurry was placed on a small glass slide and allowed to dry. The resulting film was examined by both X-ray diffraction and X-ray emission. The former test was made with an X-ray diffractometer using nickel-filtered copper radiation.

Results

8. Inspection of the nine cores showed that the six 4-in. diameter cores were about 4 ft long and were usually in two pieces of approximately equal lengths. In addition, most of these cores showed one or more vertical

cracks that extended down from the top for about 1 ft. The three NX cores were received as fragments with the longest intact pieces about 4 in. long. They also showed vertical cracks extending down from the surface for about 1 ft.

9. The concrete seen in the cores was generally well consolidated and was not air entrained. The fine aggregate was natural sand. All of the cores contained crushed granite gneiss of about 1 in. or 1-1/2 in. maximum aggregate size. The petrographic report in Reference 1 refers to this material as granite, but it is believed that granite gneiss is a better descriptive term for this material. All of the cores except No. 9 also contained quartz and quartzite gravel of about 3/4 in. maximum size.

10. The concrete showed alkali-silica reaction, as white alkali-silica gel in air voids and coating old fracture surfaces, as internally cracked coarse aggregate particles, and as reaction rims on some of the granite gneiss coarse aggregate particles. All of these manifestations of reaction are as described in Reference 2. While all of the cores showed evidence of this reaction, core 11 showed more abundant signs of reaction and was more cracked than the other cores (Figure 3).

11. The alkali-silica gel was perceptibly crystalline, showing a salt and pepper type of texture when viewed in a powder immersion mount with a polarizing microscope. Its refractive index was between 1.460 and 1.500. It gave a complex X-ray diffraction pattern which was similar to patterns of other alkali-silica gels reported in References 3 and 4. X-ray emission spectroscopy showed its major elements to be calcium, potassium, and silicon. This also is similar to results reported in Reference 3. Sodium and water, although probably present, would not be detected by this technique. The X-ray diffraction pattern appears to consist of several poorly crystalline hydrous calcium silicates and several forms of calcium carbonate; the latter probably include calcite, aragonite, and vaterite. These calcium carbonates represent carbonation of the gel. The hydrous calcium silicates show similarities to powder diffraction cards[5] 12-109 for calcium silicate hydrate ($Ca_3SiO_5 \cdot 1.5H_2O$) and 18-1206 for jennite ($Na_2Ca_8Si_5O_{30}H_{22}$).

12. Excellent reaction rims on some granite gneiss particles were seen. Some of those in core 11 are shown in Photograph 1. The rims on the gravel particles may also be reaction rims, but it is always possible with natural gravel particles that such rims are a weathering phenomenon unrelated to the alkali-silica reaction and were present before the gravel was placed in concrete. Photograph 2 is an enlarged view of a reaction rim on one piece of granite gneiss. These rims are not detectable in thin sections that are known to include such rimmed particles.

13. Of all the methods that were used to search for alkali-silica reaction, the examination of broken surfaces and of plane prepared surfaces with a stereomicroscope was the most useful technique.

14. The length change data in Table 1 do not indicate any significant effects at this time. This test will continue and the District will be advised if significant changes do occur.

15. Table 2 shows the ultrasonic pulse velocity and compressive strength data for five of the six larger diameter cores. Core 11 was not included since it was cracked for most of its length. None of the NX cores, 15, 16, or 17, are included since the pieces were too short to be tested. The pulse velocity values range from 12,500 to 14,680 feet per second (fps) and average 12,130 fps. In December of 1974, 12 ultrasonic pulse velocity values from 3 locations in the land wall of this lock ranged from 12,490 to 14,900 fps and averaged 13,720 fps.[6] While all of the values are for the land wall the exact correlation of core locations to locations in Reference 6 is not known. The values from the cores represent vertical shots while the others[6] range from horizontal to diagonally downward. All of the values are quite similar in range and somewhat less similar as averages.

16. The compressive strength values in Table 2 range from 4920 to 6800 psi and average 5860 psi for 13 specimens. The location of core 9 is close to core 7 from Reference 1 so it is of interest to compare the compressive strength values for the two cores. The values for two specimens from core 9 were 5570 and 5760 psi (Table 2) while Reference 1 shows 7190 psi for core 7. The agreement is not particularly good by this comparison as 7190 psi seems unusually high considering the other compressive strength values in Table 2 and Reference 1.

Discussion

17. As stated earlier, the concrete represented by these cores shows definite evidence of alkali-silica reaction. It seems probable that the reaction was present before the previous examination,[1] but the criteria of reaction involving granitic aggregate were less well known and accepted before the publication of Reference 2.

18. While there was some calcium sulfoaluminate seen in cracks and on broken surfaces of the cores, the amount appeared to be normal. Although the concrete was not air entrained, its appearance and physical condition did not indicate that any significant frost damage had occurred. Therefore, it is believed that much or all of the cracking seen in this structure is due to the alkali-silica reaction.

19. Reference 7 states that Penn-Dixie and Lehigh portland cements were used in this structure with Penn-Dixie used in the lock walls. However, no records have been recovered to show the alkali content of either cement.

Mr. Earl Titcomb of the US Army Engineer District, Savannah, has said* that the granite gneiss coarse aggregate may be from the Camak Quarry or one in that region that was working in the same rock mass when this structure was built. The material from the Camak Quarry was one of the sources for the coarse aggregate found to be reactive in some Georgia highway bridges.[2]

20. The presence or absence of the quartz and quartzite gravel was not a controlling factor in the deleterious reaction that occurred since evidence of reaction was found in cores with and without the gravel. In addition, it is now known that such material as this gravel may also be reactive in some cases.[3]

21. This second finding of alkali-silica reaction in concrete structures in Georgia involving similar granite gneiss suggests that this reaction may be more widespread than was recognized. Additional investigations of other concrete structures in this geographic area could provide valuable information on the reactivity of this granite gneiss aggregate in other environments and with other cements, especially if service record and source data could be obtained.

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* Personal communication.

References

1. Letter with 1 incl from J. G. Higgs of US Army Engineer District, Savannah, to Division Engineer, US Army Engineer Division, South Atlantic, dated 3 August 1973, subject: New Savannah Bluff Lock and Dam - Petrographic Examination of Concrete Cores for Reactive Aggregates and Concrete Strength Tests.

2. Mather, K., "Examination of Cores from Four Highway Bridges in Georgia," US Army Engineer Waterways Experiment Station, CE, Miscellaneous Paper C-73-11, Vicksburg, Miss., November 1973.

3. Buck, A. D., and Mather, K., "Concrete Cores from Dry Dock No. 2, Charleston Naval Shipyard, S. C.," US Army Engineer Waterways Experiment Station, CE, Miscellaneous Paper C-69-6, Vicksburg, Miss., June 1969.

4. US Army Engineer Waterways Experiment Station, Concrete Laboratory, Petrographic Report dated 3 May 1974, subject: Examination of Fontana Dam Concrete Cores.

5. Powder Diffraction File, Joint Committee on Powder Diffraction Standards, publication SMA-26, Swarthmore, Pa., 1976.

6. Letter with 1 incl from B. Mather, Chief, Concrete Laboratory, to District Engineer, US Army Engineer District, Savannah, dated 26 February 1975, subject: Ultrasonic Pulse Velocity Survey, Hartwell Dam and New Savannah Bluff Lock and Dam.

7. "New Savannah Bluff Lock and Dam, Savannah River, Georgia and South Carolina, Periodic Inspection Report No. 1," US Army Engineer District, Savannah.

Table 1

Length-Change Data for Three Concrete Cores*
from the Land Wall of New Savannah Bluff Lock

Core	Depth, ft	Length-Changes at Days Indicated, Percent**					
		7	14	21	28	56	84
9	2.2 - 3.0	0.02	0.02	0.01	0.03	0.03	0.03
11†	2.1 - 3.0	0.00	0.00	0.01	0.01	0.00	
14	1.5 - 2.3	0.00	0.00	0.00	0.00	0.00	0.00

* Each specimen was a portion of a 4-in. diameter core.

** Specimens were stored at 100 percent relative humidity and 100°F.

† Measured at 9 and 15 days instead of at 7 and 14 days.

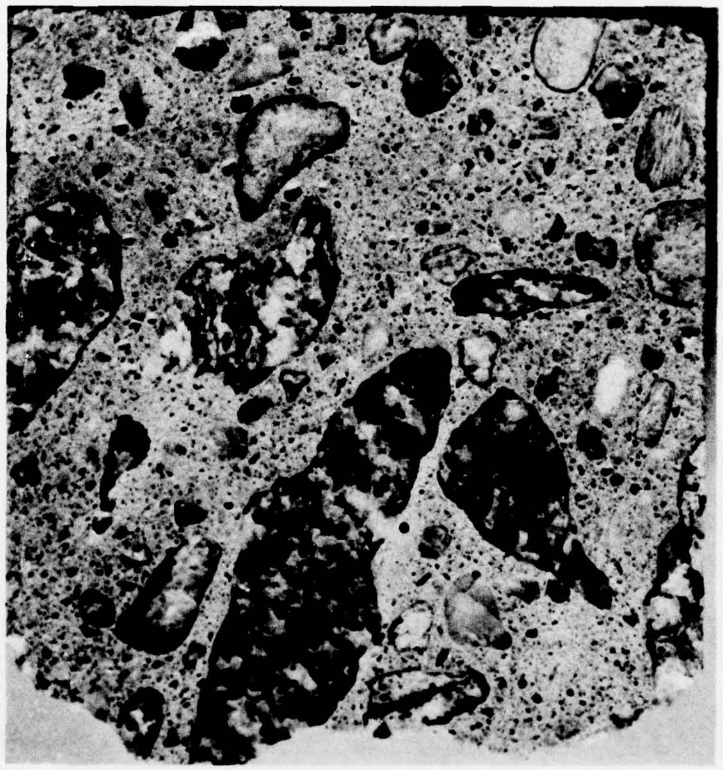
Table 2

Laboratory Data for Five Vertical Concrete Cores* from the Land Wall of New Savannah Bluff Lock

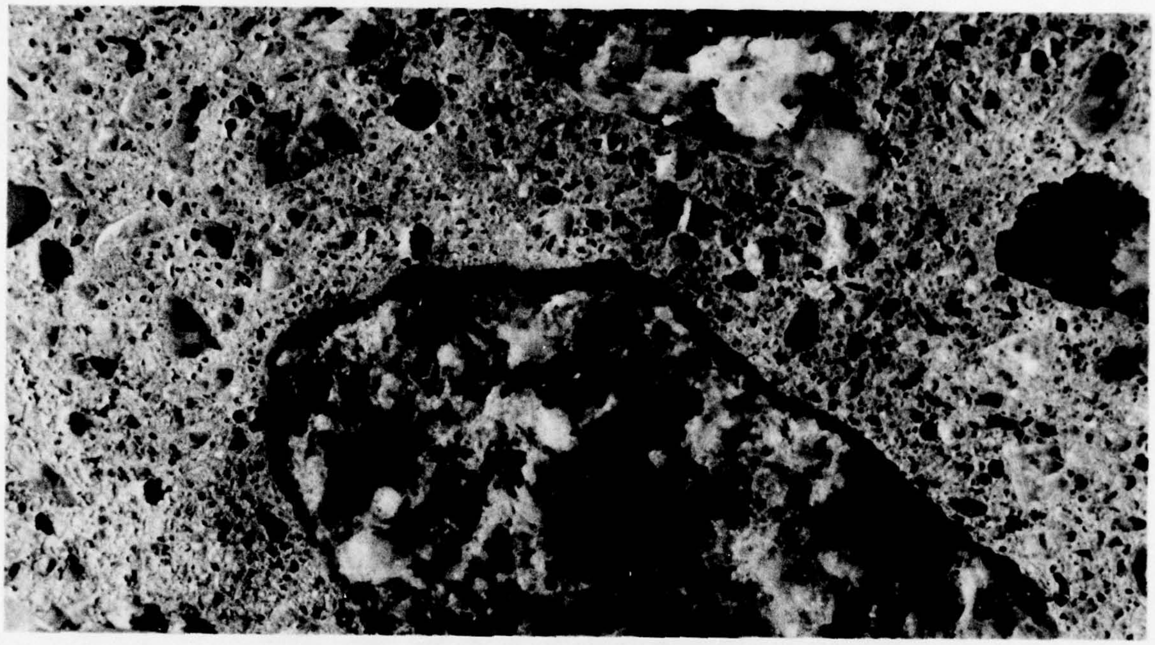
Location	Core No.	Core Depth, ft	Ultrasonic Pulse Velocity, fps		Compressive Strength, psi**
Sta 0+76.4B	9	2.2 - 4.0	12,500		5760
					5570
				Average	5660
Sta 1+29.7B	10	1.9 - 3.9	14,120		6410
					6320
					5630
				Average	6120
Sta 3+43.6B	12	2.4 - 4.0	14,680		6800
					6320
				Average	6560
Sta 3+44.6B	13	0.0 - 1.2	13,860		4920
					5700
		1.4 - 2.9	14,120		5700
					6320
				Average	5660
Sta 4+25.1B	14	1.5 - 4.0	13,510		5770
					4960
				Average	5360
Range			12,500 to 14,680		4920 to 6800
Average			12,130		5860

* 4-in. diameter.

** Tested according to CRD-C 27-69, Handbook for Concrete and Cement.



Photograph 1. Sawed and ground surface of concrete core 11 between 3.8 and 4.2 ft, about 1X. Several pieces of the black and white granite gneiss coarse aggregate show reaction rims believed to be due to alkali-silica reaction.



Photograph 2. Enlargement of granite gneiss particle on left side of core in Photograph 1, about 3.5X. The reaction rim is apparent.

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1. Alkali aggregate reactions. 2. Concrete cores. 3. Concrete cracking. 4. New Savannah Bluff Lock and Dam. I. United States. Army. Corps of Engineers. Savannah District. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; C-78-13.
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