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# POTENTIAL ALKALI-CARBONATE ROCK REACTIVITY OF SOME OF THE AGGREGATE USED IN FISHTRAP DAM

by

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Two samples of carbonate rock coarse aggregate were obtained from the quarry that furnished some of the coarse aggregate for Fishtrap Dam. These materials were subjected to petrographic examination. Small rock cores were prepared from some of these aggregate particles and tested for length change in sodium hydroxide solutions. Five concrete mixtures were made in the laboratory using these aggregates; specimens from these mixtures were tested

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for length change during moist storage or during storage in laboratory air followed by moist storage; other specimens were tested for compressive strength.

Six concrete cores from the spillway portion of Fishtrap Dam were received in the laboratory. They were inspected and photographed. Thin sections were made and selected specimens were tested for length change during moist storage.

It was concluded that an alkali-carbonate rock reaction had occurred at Fishtrap Dam. There was no indication that this was a deleterious reaction. It is likely that the use of low-alkali portland cement and relatively small aggregate size served to keep the reaction at a safe level. It is also possible that natural dilution of the reactive rock by innocuous rock had a moderating effect on the reaction.

# PREFACE

This work was authorized by the U. S. Army Engineer District, Huntington, by 1st Indorsement dated 4 March 1971, subject: Proposed Investigation of Fishtrap Dam Concrete and Aggregate for Carbonate Rock Reaction. The work was conducted in the Concrete Laboratory (CL) of the U. S. Army Engineer Waterways Experiment Station (WES) under the direction of Messrs. Bryant Mather, R. V. Tye, Jr., Leonard Pepper, and Mrs. Katharine Mather during the period between June 1971 and June 1976. Mr. A. D. Buck was the project leader and prepared this report.

The Directors of WES during this period were BG E. D. Peixotto, CE, and COL G. H. Hilt, CE. 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 |
|---|---|---|
| inches | 25.4 | millimetres |
| pounds-mass | 0.4536 | kilograms |
| pounds-force per square inch | 0.00689476 | megapascals |
| feet | 0.3048 | metres |

# POTENTIAL ALKALI-CARBONATE ROCK REACTIVITY OF SOME OF THE AGGREGATE USED IN FISHTRAP DAM

## PART I: INTRODUCTION

1. Portions of Fishtrap Dam, located near Pikeville, Kentucky, were built using a carbonate aggregate which later laboratory work[1] indicated was potentially reactive in an alkali-carbonate rock reaction. When this reaction occurs in concrete it may result in cracking and subsequent deterioration.[2] Therefore, a combination of field inspections and laboratory tests were made to determine if the reaction occurred and if it did or would cause distress of the concrete.

## PART II: MATERIALS

2. Two samples of carbonate coarse aggregate were received (1971, 1974) from the quarry which had produced the potentially reactive aggregate for Fishtrap Dam approximately 5 years earlier. These samples were identified as HUN-2 G-4(2, 3), zones A through D.

3. Two innocuous carbonate sands were used as fine aggregate at different times in the laboratory. One was identified as CRD-MS-17(5) and the other as CRD-MS-27.

4. Two portland cements were used in the laboratory. One was a low-alkali cement identified as RC-656; the other was a high-alkali cement identified as RC-272.

5. Six 6-in. diameter concrete cores from the spillway portion of Fishtrap Dam were received in November 1972. They contained the coarse aggregate that was expected to be reactive. The cores are identified below:

| Concrete Laboratory Serial No. | Field Data |
|---|---|
| HUN-5 DC-1 | Horizontal core No. M-1L from the left training wall at the upstream end of the spillway. |
| HUN-5 DC-2 | Horizontal core No. M-1R from the right training wall at the upstream end of the spillway. |
| HUN-5 DC-3 | Horizontal core No. M-5R from the right training wall at the downstream end of the spillway. |
| HUN-5 DC-4 | Horizontal core No. M-9R from the right training wall at the downstream end of the spillway. |
| HUN-5 DC-5 | Vertical core from Apron No. 1, spillway floor. |
| HUN-5 DC-6 | Vertical core from Apron No. 2, spillway floor. |

# PART III: PROCEDURES

6. Portions of the concrete in the Fishtrap Dam project were examined in May 1970 and again in May 1972 by an inspection party; a representative of the Concrete Laboratory (CL) was present at each inspection.

7. Data concerning cements, concrete mixtures, etc., were made available by the U. S. Army Engineer District, Huntington.

8. The two rock shipments consisted of 3- to 6-in. particles that had been selected and bagged by District personnel to represent zones A through D in the quarry. All of the particles in each shipment were examined and classified in rock types. Representative particles were selected for petrographic and length-change tests. The remainder of each shipment was processed into aggregate passing the 3/4-in. sieve. The absorption and specific gravity of the processed rock were determined by CRD-C 107.[3]

9. The different rock types that were separated by petrographic examination were characterized as follows:

- a. A slice, 1 in. thick, was cut from each of 14 pieces of the 1971 shipment; one of these sawed surfaces was acid-etched and then inspected to determine composition and texture.
- b. Portions of 12 of these 14 pieces were ground, most to pass a No. 325 sieve, and the powders were examined by X-ray diffraction to determine their composition. Wherever possible, the amount of dolomite was determined by the method of Tennant and Berger.[4] The X-ray patterns were made with an X-ray diffractometer using nickel-filtered copper radiation.
- c. Small rock cores from 10 of the particles were tested for length-change in sodium hydroxide solution by CRD-C 146;[3] two cores from a black piece from the 1974 shipment of rock were also tested according to CRD-C 146.

10. Two concrete mixtures were made with the 1971 shipment of rock. The coarse aggregate was combined as follows:

| Zone | Percent |
|---|---|
| A | 31 |
| B | 15 |
| C | 31 |
| D | 23 |

The intent was to use the coarse aggregate in about the proportions that represented quarry production while the project was being constructed.[1] One mixture was made with low-alkali cement and one with high-alkali cement. Both mixtures were made to the control parameters of CRD-C 114.[3]

11. Concrete bars, each 2 by 2 by 11-1/4 in. with gage studs in the ends, were cast from each mixture. Three bars from each mixture were stored continuously in a moist environment and measured periodically for length-change for 3 years. Three other bars per mixture were stored in laboratory air for 12 months, put in water for 48 hr, and then kept continuously moist for an additional 2 years; they were read periodically with the other bars.

12. The concrete cores were photographed and nominal 12-in. lengths were cut from four of them (HUN-5 DC-1, -4, -5, -6) and fitted with metal inserts; they were measured for length-change over a 3-year period during continuous moist storage. Thin sections were made from unused portions of cores HUN-5 DC-1 and -5 and examined with a petrographic microscope. Some of these sections were photographed during their preparation to illustrate the presence of reaction rims on some aggregate particles. Sawed surfaces of portions of HUN-5 DC-1 and -5 were etched in dilute hydrochloric acid; these surfaces were examined before and after etching to determine the effect of this etching on the reaction rims around 17 aggregate particles.

13. Since the results obtained with the 1971 shipment of rock and the concrete cores were inconclusive, the larger sample of rock was obtained in 1974. It was examined and classified as before; concrete mixtures using it were made as before and length-change tests were made. The differences in the work done with the 1974 shipment of rock are listed below:

a. Only one piece of black rock was tested for length-change by CRD-C 146.[3]

b. In addition to repeats of two concrete mixtures, one mixture was made using only the zone A rock as coarse aggregate with high-alkali cement.

c. All of the length-change measurements were made on concrete bars that were kept continuously moist.

d. The compressive strengths of 3- by 6-in. concrete cylinders were determined at 28, 90, and 371 day ages.

e. A partial repeat chemical analysis of cement RC-272 was made to verify its high alkali content before it was used with the 1974 shipment of rock.

## PART IV: RESULTS AND DISCUSSION

### Field Inspections

14. Evidence that a form of alkali-carbonate rock reaction has occurred in concrete is usually found as reaction rims that are visible around the edges of affected carbonate aggregate particles.[2, 5] Such rims were found in the concrete of Fishtrap Dam appurtenances during the 1972 inspection of the dam. District personnel took photographs of these rims during this inspection. More visible reaction rims were found in the concrete cores received in 1972; examples of these are shown in Photograph 2. Therefore, it can be said that an alkali-carbonate rock reaction has occurred in the Fishtrap Dam concrete appurtenances.

### Field Data

15. All of the cements available in the Huntington District when Fishtrap was built were low alkali cements. The maximum aggregate size was 3 in. The potentially reactive aggregate was used in the intake structure above elevation 679 ft and in the spillway. The spillway should have little or no contact with water, ~~other than rainwater or~~ groundwater, while portions of the intake structure are in continuous contact with lakewater.

### Carbonate Rock

16. The compositions of the two rock shipments are shown in Table 2 by quarry production zones A through D and also as total compositions. There were five recognizable rock types present with two of them making up the bulk of most zones and of the total samples. Brief descriptions of the rock types follow:

a. Fine-grained argillaceous black limestone. Some of this rock contained a small amount of black chert; most of the rock was fossiliferous. X-ray diffraction examination of five pieces indicated that it was impure limestone and impure dolomitic limestone. The dolomite content was less than 5 percent by the method of Tennant and Berger.[4] The impurities consisted of quartz, feldspar, pyrite, kaolinite, clay-mica, and in some pieces, chlorite. This rock type was a major constituent of zones A and C and amounted to about 30 percent of the total sample (Table 2). The length-changes of small cores from six pieces of this rock type are shown in Table 3; one of the six pieces is classified as reactive, with expansion of 0.21 percent by 84 days;[5] cores from the other five pieces expanded 0.1 percent or more during 2 years of testing. Pieces 4A and 4B from the original sample from this source[1] were of this rock type. The average expansion of several cores from each of these pieces is compared with the average expansion of 12 cores from the present 6 pieces in Figure 1; it is obvious that the 1971 and 1974 samples of this rock type are much less expansive than the samples tested in the 1960's. This difference may be due to the fact that the original samples contained more dolomite.[1]

b. <u>Fine-grained brownish limestone to argillaceous dolomitic limestone.</u> The category covers a wide range in composition, but the general appearance of all of this rock is similar. It contained less than 5 percent dolomite; the noncarbonate material was montmorillonitic clay and quartz and in some pieces kaolinite and clay-mica or clay-mica. This rock was the major category of zones B and D and was calculated to be 57 percent of the entire 1971 and 1974 samples (Table 2). The length-changes of cores from four pieces of this rock type are shown in Table 3; one piece expanded 0.1 percent by 84 days of testing; two of the other three pieces expanded more than 0.1 percent during 6 months of testing. Piece 4D from the earlier work[1] was this type of rock. The average length-change of two cores from piece 4D is compared with the average length-change of eight cores from four pieces of this rock in Figure 2; past and present results are similar.

c. <u>Fine-grained calcitic dolomite.</u> This material ranged from bluish to grayish in color. It contained about 42 percent dolomite. Noncarbonate minerals were chlorite, clay-mica, kaolinite, quartz, and feldspar. This rock type amounted to 29 percent of the 1971 zone A material but was usually less than 10 percent by zones or entire sample (Table 2). Length-change data for one piece of this material are shown in Table 3; it expanded 0.21 percent during the first 28 days of testing. This material is similar to piece 4C from the original sample.[1]

d. <u>Fine-grained reddish argillaceous limestone to dolomitic limestone.</u> This was a minor rock type found in zones C and D; it amounted to about 4 percent of the total sample

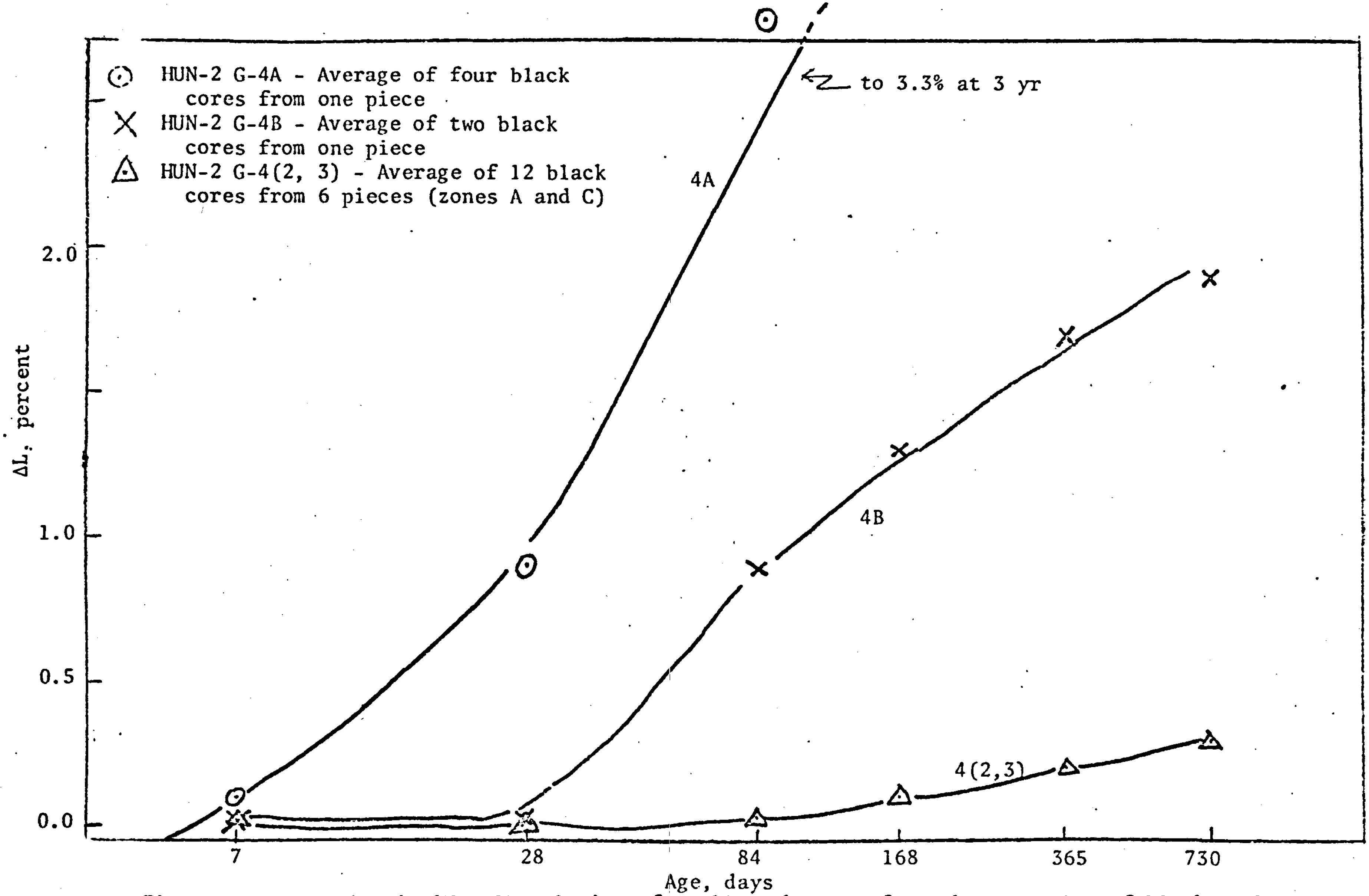



Figure 1. Expansion in 1N NaOH solution of small rock cores from three samples of black rocks. Samples obtained during a 10-yr period.

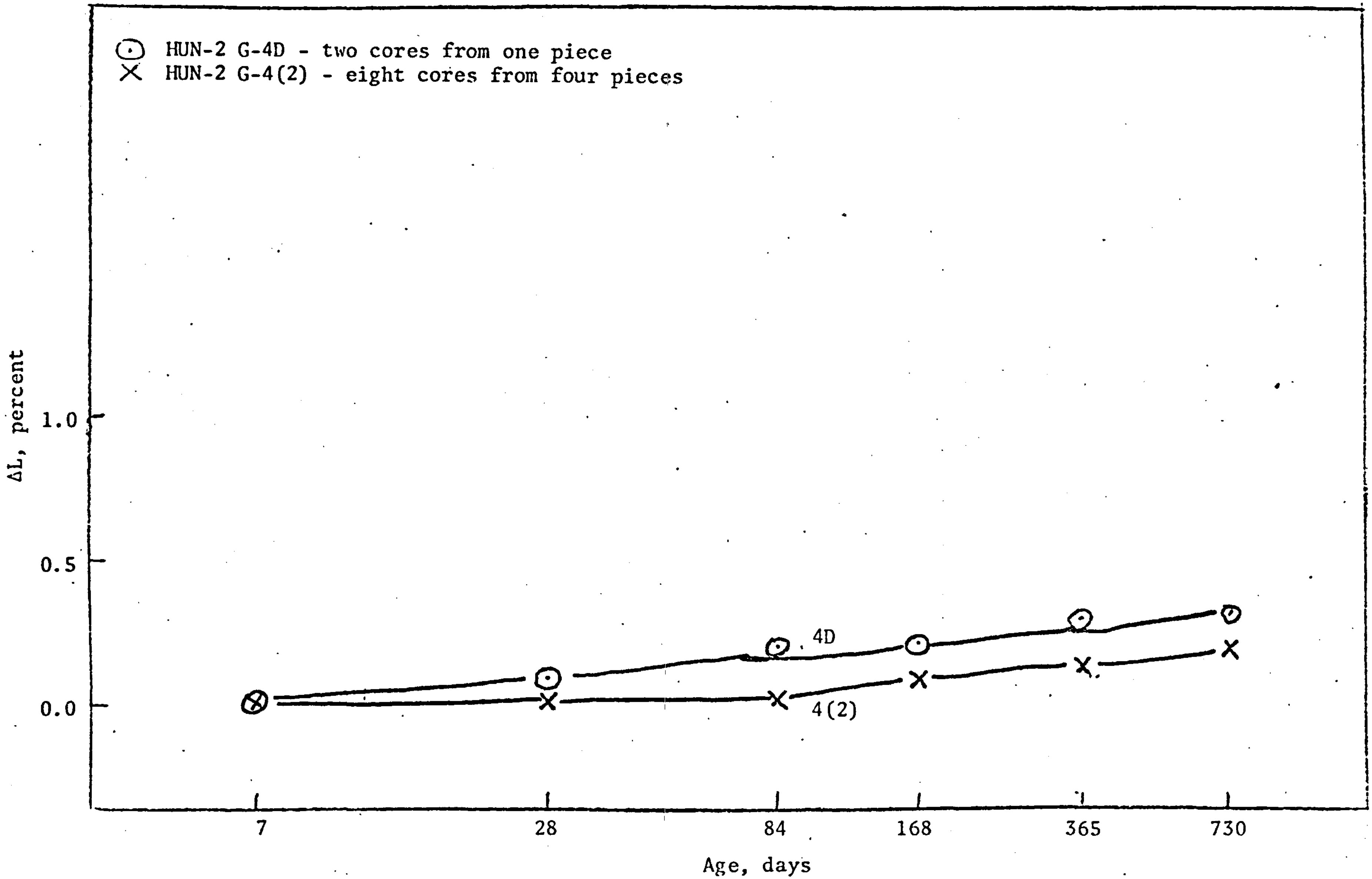



Figure 2. Expansion in 1N NaOH solution of small rock cores from two samples of brownish rock.

(Table 2); some pieces were fossiliferous or oölitic. No length-change tests of this type were made since it was minor in amount.

e. Fine-grained light olive gray (5Y 6/1)[6] oölitic limestone. A few pieces of this material were found in each zone and amounted to about 3 percent of the total sample (Table 2). No length-change tests were made.

17. Individual and weighted average values for specific gravity and absorption of the 1971 and 1974 samples are shown below:

| | Specific Gravity | | Absorption, percent | |
|---|---|---|---|---|
| | Sample HUN-2G- | | Sample HUN-2G- | |
| Zone | 4(2) | 4(3) | 4(2) | 4(3) |
| A | 2.71 | 2.69 | 0.8 | 0.8 |
| B | 2.67 | 2.70 | 1.2 | 0.7 |
| C | 2.66 | 2.70 | 0.9 | 0.6 |
| D | 2.66 | 2.70 | 1.2 | 0.6 |
| Weighted average | 2.67 | 2.69 | 1.0 | 0.7 |

These values are similar to those found earlier.[1]

## Laboratory Concrete

18. Chemical data for the low- and high-alkali cements that were used are shown in Table 1. The partial recheck of RC-272 that was made in 1974 verified its high alkali content.

19. Compressive strength values for the three concrete mixtures made with the 1974 aggregate sample (HUN-2G-4(3)) are shown in Table 4. They show normal results.

20. Length-change data for five concrete mixtures are shown in Table 5. Two of the mixtures were made with the 1971 aggregate sample; the other three mixtures were made with the 1974 aggregate sample. None of the data through 36 months of measurement indicate any significant expansion. Work reported in 1975[7] showed that significant expansion does occur for concrete specimens containing an adequate amount of reactive rock and high-alkali cement. The data in Table 5 indicate that the 1971 and 1974 samples are not significantly expansive.

## Concrete Cores

21. The appearance of the six cores is shown in Photograph 1. They do not show any evidence of deleterious reaction even though they do contain many aggregate particles that show reaction rims (Photograph 2). Acid-etching of 17 rimmed aggregate particles developed 2 negative rims; one each on a blackish and a brownish particle. The other particles did not show positive or negative rims.[2, 8]

22. Length-change data for specimens from four of these cores during moist storage are shown in Table 6. The data do not indicate significant expansion.

## Comment

23. The variety of rock types found during the examination of the 1971 and 1974 samples shows clearly that the original sampling of one piece of rock for a 40- to 80-ft ledge[1] was inadequate. Length-change testing of those four pieces of rock indicated large expansions and potential reactivity of that aggregate;[1] this prediction was verified by the presence of reaction rims on aggregate particles in the project concrete.

24. The length-change data for typical rock types from the 1971 and 1974 aggregate samples show less expansion and suggest a slow and limited reactivity. The lack of significant length change of concrete specimens made with these aggregates and high-alkali cement in the laboratory indicates that if an alkali-carbonate rock reaction is occurring, it is negligible in effect.

25. The overall difference between the potential reactivity indicated by original data[1] and shown by the 1971 and 1974 samples as rock and in concrete indicates that the quarry production was less reactive in 1971 and 1974.

# PART V: CONCLUSIONS

26. The work reported in Reference 7 indicates that existing procedures for detecting potentially reactive carbonate rocks and for controlling this potential for reaction and expansion are generally adequate.[5] Therefore, it is concluded that:

a. An alkali-carbonate rock reaction has occurred in some of the Fishtrap Dam concrete.

b. No deleterious expansion has occurred nor is likely to occur because of this reaction. This is probably so because of the use of low-alkali cement and relatively small aggregate size. It is also possible that the level of reactive rock in the project aggregate was low enough to provide some protection against deleterious reaction by the dilution effect.[5]

## REFERENCES


1. Buck, A. D., "Potential Alkali Reactivity of Carbonate Rock from Six Quarries," Miscellaneous Paper C-69-15, Oct 1969, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

2. "Symposium on Alkali-Carbonate Rock Reactions," Highway Research Board Record No. 45, National Academy of Sciences - National Research Council, Washington, D. C., 1964.

3. U. S. Army Engineer Waterways Experiment Station, CE, Handbook for Concrete and Cement, Aug 1949 (with quarterly supplements), Vicksburg, Miss.

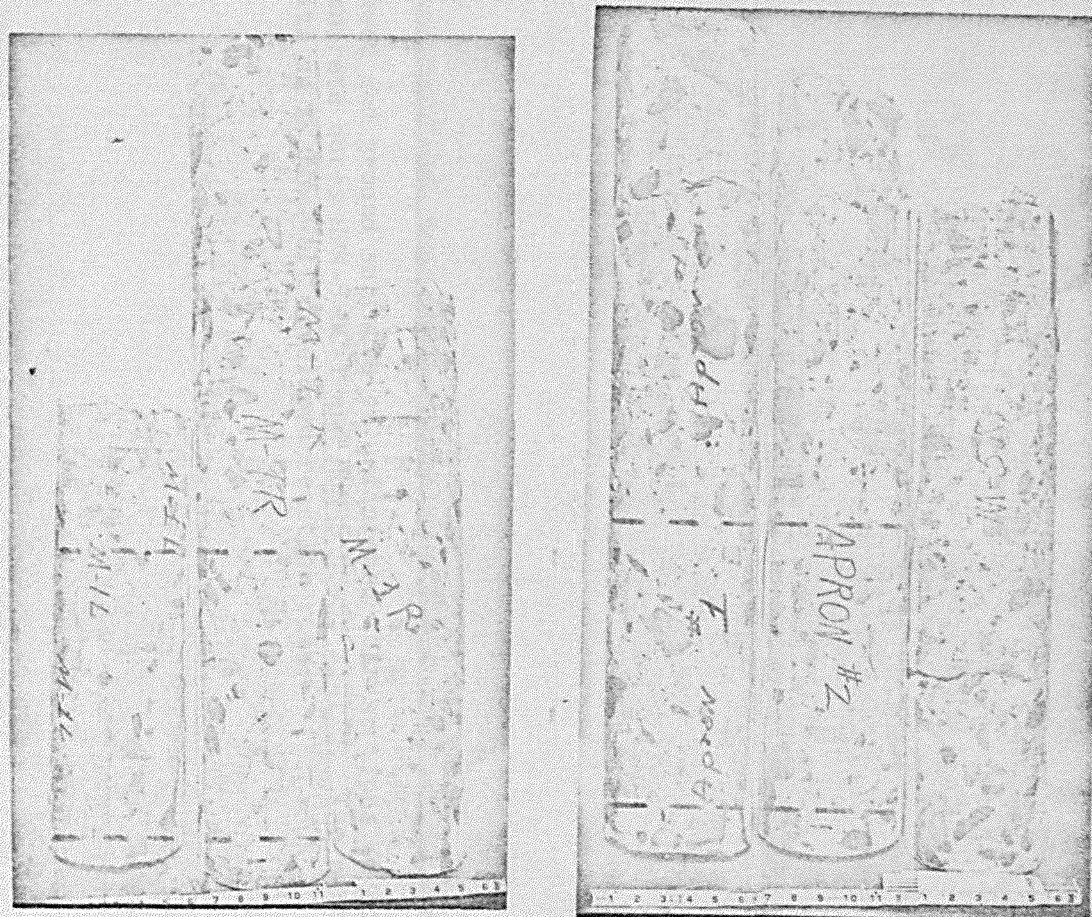
4. Tennant, C. B. and Berger, R. W., "X-Ray Determination of the Dolomite-Calcite Ratio of a Carbonate Rock," American Mineralogist, Vol 42, No. 1 and 2, 1957, pp 23-29.

5. Department of the Army, Office, Chief of Engineers, "Standard Practice for Concrete," Appendix C, Engineer Manual 1110-2-2000, Nov 1971, Washington, D. C.

6. The Rock-Color Chart Committee, National Research Council, Rock-Color Chart, Washington, D. C., 1963.

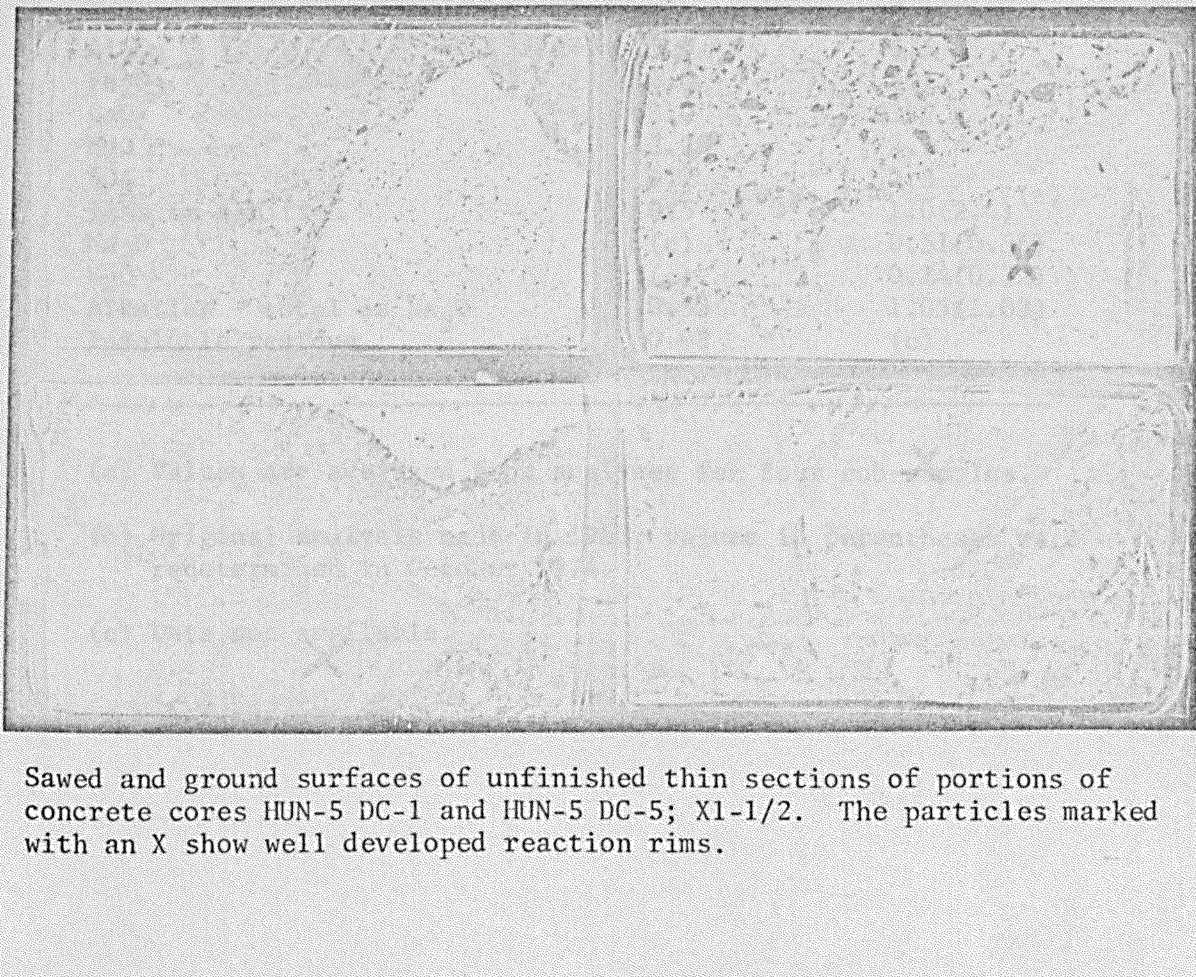
7. Buck, A. D., "Control of Reactive Carbonate Rocks in Concrete," Technical Report C-75-3, Sep 1975, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

8. Buck, A. D. and Dolch, W. L., "Investigation of a Reaction Involving Nondolomitic Limestone Aggregate in Concrete," Miscellaneous Paper 6-782, Jan 1966, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.




Appearance of six concrete cores from Fishtrap Dam. The portions within the dotted lines were used for length-change tests.

Photograph 1



Sawed and ground surfaces of unfinished thin sections of portions of concrete cores HUN-5 DC-1 and HUN-5 DC-5; X1-1/2. The particles marked with an X show well developed reaction rims.

Photograph 2

Table 1

Test Data on Two Portland Cements

| Chemical Data | | |
|---|---|---|
| Amounts, Percent | RC-656[(a)] | RC-272 |
| $SiO_2$ | 21.7 | 20.1 |
| $Al_2O_3$ | 5.0 | 6.5 |
| $Fe_2O_3$ | 4.0 | 3.1 |
| CaO | 63.0 | 63.4 |
| MgO | 3.7 | 3.1 |
| $SO_3$ | 1.7 | 2.3 |
| Loss on ignition | 0.5 | 1.0(2.4)[(b)] |
| $Na_2O$ | (c) | 0.51(0.56) |
| $K_2O$ | (c) | 0.74(0.72) |
| Alkalies - total as $Na_2O$ | 0.53 | 1.05(1.03) |
| Insoluble residue | 0.08 | (c) |

(a) Values are averaged from analyses for four sub-samples.

(b) Original analysis made in 1953; values in parentheses were redetermined in October 1974.

(c) Data not available.

Table 2

Composition of Two Samples of Carbonate Aggregate (HUN-2 G-4(2,3))[(a)] from One Quarry

| Rock Types | Composition of Aggregate by Zones, % | | | | | | | | Composition of Whole Samples, % | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Zone A | | Zone B | | Zone C | | Zone D | | | | |
| | 2 | 3 | 2 | 3 | 2 | 3 | 2 | 3 | 2 | 3 | (b) |
| Fine-grained argillaceous black limestone | 53 | 73 | -- | 12 | 47 | 8 | 4 | -- | 27 | 23 | 30 |
| Fine-grained brownish limestone to argillaceous dolomitic limestone | 18 | 9 | 94 | 82 | 18 | 92 | 80 | 100 | 50 | 71 | 57 |
| Fine-grained bluish calcitic dolomite | 29 | 7 | -- | 6 | -- | -- | -- | -- | 8 | 3 | 6 |
| Fine-grained reddish argillaceous limestone to dolomitic limestone | -- | -- | -- | -- | 18 | -- | 12 | -- | 8 | -- | 4 |
| Fine-grained light olive gray oölitic limestone | -- | 11 | 6 | -- | 17 | -- | 4 | -- | 7 | 3 | 3 |
| TOTALS | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

(a) Sample 2 was approximately 350 lb of 3-6 in. particles received 14 Jul 71. Sample 3 was approximately 1100 lb of 3-6 in. particles received 30 Aug 74 from the same quarry.

(b) Average zone compositions of 2 and 3 were combined with approximate quarry production by zones during construction of Fishtrap Dam to calculate a total composition.

Table 3

Length-Change of Small Rock Cores of HUN-2 G-4(2,3) in Sodium Hydroxide*

| Identification of Samples | | | | Average Length-Change at Ages Shown, Percent** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | † | Piece | Zone | 7 days | 28 days | 84 days | 140 days | 168 days | 196 days | 274 days | 1 year | 2 years |
| Black limestone | (2) | 1 | A | -0.01 | -0.01 | -0.01 | zero | -0.01 | -0.01 | 0.01 | 0.03 | 0.10 |
| Black limestone | (2) | 2 | A | zero | 0.12 | 0.21 | 0.23 | 0.25 | 0.27 | 0.30 | 0.34 | 0.47 |
| Black limestone | (2) | 3 | A | zero | zero | 0.04 | 0.09 | 0.09 | 0.11 | 0.19 | 0.22 | 0.43 |
| Black limestone | (2) | 10 | C | 0.01 | zero | -0.01 | zero | zero | 0.01 | 0.03 | 0.07 | 0.17 |
| Black limestone | (2) | 11 | C | zero | -0.01 | zero | zero | zero | 0.01 | 0.08 | 0.11 | 0.24 |
| Black limestone | (3) | 1 | A | -0.01 | 0.01 | 0.03 | †† | †† | †† | 0.09 | 0.15 | †† |
| Average of black | | | | zero | 0.02 | 0.04 | 0.06 | 0.07 | 0.08 | 0.12 | 0.15 | 0.28 |
| Calcitic dolomite | (2) | 5 | A | 0.05 | 0.21 | 0.44 | 0.57 | 0.64 | 0.70 | 0.87 | 0.99 | 1.16 |
| Brownish dolomitic limestone | (2) | 6 | B | -0.02 | -0.02 | -0.01 | -0.02 | -0.02 | -0.01 | -0.02 | -0.01 | 0.01 |
| Brownish dolomitic limestone | (2) | 7 | B | -0.01 | -0.02 | zero | 0.01 | 0.02 | 0.02 | 0.03 | 0.02 | 0.03 |
| Brownish dolomitic limestone | (2) | 12 | D | zero | 0.01 | 0.04 | 0.11 | 0.15 | 0.18 | 0.27 | 0.30 | 0.40 |
| Brownish dolomitic limestone | (2) | 13 | D | -0.01 | zero | 0.09 | 0.16 | 0.20 | 0.23 | 0.30 | 0.32 | 0.36 |
| Average of brownish type | | | | -0.01 | -0.01 | 0.03 | 0.06 | 0.09 | 0.10 | 0.14 | 0.16 | 0.20 |

* CRD-C 146, Reference 1.
** Values are positive unless preceded by a minus sign.
† Refers to aggregate shipment.
†† Data not available.

Table 4

Compressive Strength Data for Three Concrete Mixtures

| Mixture Identification | Compressive Strengths of 3 by 6 in. Cylinders at Ages Shown, psi | | |
|---|---|---|---|
| | 28 days | 90 days | 371 days |
| Mixture A: All zone A rock from HUN-2 G-4(3) coarse aggregate; high-alkali cement RC-272 | 4360 | 5620 | 5630 |
| | 3540 | 5390 | 6000 |
| | 3610 | 5470 | 6150 |
| Average | 3840 | 5490 | 5930 |
| Mixture B: Combined zones A-D rock from HUN-2 G-4(3) coarse aggregate; low-alkali cement RC-656 | 4750 | 6120 | 6970 |
| | 4880 | 6050 | 6380 |
| | 4720 | 6120 | 6880 |
| Average | 4780 | 6100 | 6740 |
| Mixture C: Combined zones A-D rock from HUN-2 G-4(3) coarse aggregate; high-alkali cement RC-272 | 3660 | 5270 | 5460 |
| | 4600 | 4540 | 5490 |
| | 4340 | 5180 | 5470 |
| Average | 4200 | 5000 | 5470 |

Table 5

Length-Change of Seven Groups of Concrete Bars

| Identification of Mixtures | Average Length-Change at Ages Shown, Percent (a)(b) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 7 days | 28 days | 56 days | 84 days | 6 months | 12 months | 24 months | 36 months |
| Mixture A made with zone A rock from HUN-2 G-4(3) coarse aggregate and high-alkali cement RC-272 | (c) | (c) | 0.01 | 0.01 | 0.01 | 0.02 | (d) | (d) |
| Mixture B made with blend of zones A-D from HUN-2 G-4(3) coarse aggregate and low-alkali cement RC-656 | (c) | (c) | 0.01 | 0.01 | 0.01 | 0.01 | (d) | (d) |
| Same as B but made from earlier shipment of rock | (c) | (c) | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 |
| (HUN-2 G-4(2)) (e) | -0.04 | -0.06 | -0.06 | -0.06 | -0.06 | -0.07 | -0.03 | -0.02 |
| Mixture C made with blend of zones A-D from HUN-2 G-4(3) coarse aggregate and high-alkali cement RC-272 | (c) | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | (d) | (d) |
| Same as C but made from earlier shipment of rock | (c) | (c) | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 |
| (HUN-2 G-4(2)) (e) | -0.03 | -0.06 | -0.06 | -0.06 | -0.06 | -0.07 | -0.03 | -0.02 |

(a) Each value is average of three or six bars.
(b) Values are positive unless preceded by a minus sign.
(c) Less than 0.01 percent.
(d) Measurements stopped.
(e) These bars were stored in laboratory air for 12 months and then placed in moist storage. All other bars were kept in continuous moist storage.

Table 6

Length-Change of Four Concrete Cores[a] During Moist Storage

| Core Identification | Length-Change at Ages Shown, Percent | | | | | |
|---|---|---|---|---|---|---|
| | 31 days | 63 days | 91 days | 122 days | 255 days | 2-3/4 years |
| Core HUN-5 DC-1[b] from upstream end of left training wall of spillway | 0.01 | 0.02 | 0.01 | 0.01 | (c) | 0.02 |
| Core HUN-5 DC-4[b] from downstream end of right training wall of spillway | 0.02 | 0.01 | 0.02 | 0.01 | 0.02 | 0.03 |
| Core HUN-5 DC-5[d] from Apron No. 1 of spillway floor | (c) | (c) | (c) | (c) | 0.01 | (c) |
| Core HUN-5 DC-6[d] from Apron No. 2 of spillway floor | 0.01 | (c) | (c) | (c) | (c) | (c) |

(a) Portions of 6-in.-diameter-cores from spillway area of Fishtrap Dam. They all contain carbonate aggregate that may be reactive.
(b) Maximum aggregate size is 1-1/2 in.
(c) Change was negligible.
(d) Maximum aggregate size is 3 in.

**In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.**

Buck, Alan D
Potential alkali-carbonate rock reactivity of some of the aggregate used in Fishtrap Dam, by Alan D. Buck. Vicksburg, U. S. Army Engineer Waterways Experiment Station, 1976.
1 v (various pagings) illus. 27 cm. (U. S. Waterways Experiment Station. Miscellaneous paper C-76-3)
Prepared for U. S. Army Engineer District, Huntington, Huntington, W. Va.
Includes bibliography.

1. Aggregate testing. 2. Alkali aggregate reactions. 3. Alkali carbonate rock reactions. 4. Fishtrap Dam. I. U. S. Army Engineer District, Huntington. (Series: U. S. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper C-76-3)
TA7.W34m no.C-76-3