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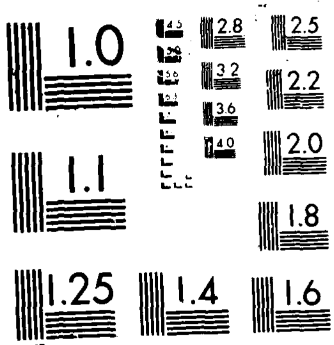
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US Army Corps of Engineers

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(2)

ALKALI-CARBONATE ROCK REACTION AT CENTER HILL DAM, TENNESSEE

by

G. Sam Wong

Structures Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

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Final Report

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Center Hill Dam, located on the Caney Fork River about 25 miles above its confluence with the Cumberland River in Dekalb County, Tennessee, is the first US Army Corps of Engineers project where alkali-carbonate rock reaction has been identified as a probable cause of cracking in the structure. Expansion of the concrete has opened joints, caused excessive leakage between some monoliths, raised the bridge over the spillway, and restricted gate movements.

Aggregate used in the concrete was produced from a quarry in limestone near the site. Examination of concrete from the structure and of rock samples from the quarry indicated that some of the aggregate used is classified as potentially reactive by the criteria given in Appendix C of the Standard Practice for Concrete (EM 1110-[illegible]).

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Preface

The work described in this report was done for the US Army Engineer District, Nashville. It was done in the Concrete Technology Division (CTD) of the Structures Laboratory (SL), US Army Engineer Waterways Experiment Station (WES) under the direction of Mr. John M. Scanlon, Chief, CTD, and Mr. Bryant Mather, Chief, SL. Mr. G. Sam Wong, CTD, was project leader and prepared this report.

The Concrete Technology Information Analysis Center (CTIAC) provided funds to publish this report; it is CTIAC Report No. 80.

COL Dwayne G. Lee, CE, is Commander and Director of WES. Dr. Robert W. Whalin is Technical Director.

Contents

	Page
Preface	1
Conversion Factors, Non-SI to SI (Metric) Units of Measurement	3
Background	4
Samples	4
Test Procedure	7
Results	8
Discussion	10
Conclusion	11
References	12
Tables 1-4	
Photos 1 and 2	
Figures 1-24	

Conversion Factors, Non-SI to SI (Metric) Units of Measurement

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
Fahrenheit degrees	5/9	Celsius degrees or kelvins*
feet	0.3048	metres

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9)(F - 32). To obtain Kelvin (K) readings, use: K = (5/9)(F - 32) + 273.15.

ALKALI-CARBONATE ROCK REACTION AT CENTER HILL DAM, TENNESSEE

Background

1. Construction of Center Hill Dam was started in 1942 and completed in 1951. The cements used for the project were from Penn-Dixie Corp., Richard City, Tennessee, and Lehigh Cement Co., Mitchell, Indiana. They were specified to comply with the requirements of Federal Specification SS-C-206a for moderate heat of hydration. No limitation on the alkali content of the cement was specified, so alkali levels are unknown.

2. The coarse and fine aggregate was from an on-site quarry located on the left bank of the river approximately 1,500 ft downstream of the dam. The quarried material was from the Ordovician Cannon Formation and consisted of a dark, compact, fine- to medium-grained rock. Some of the overlying Ordovician Catheys Formation limestone may also have been incorporated into the concrete mixtures.

3. An inspection of the structure in 1983 by the U.S. Army Engineer Nashville District indicated some problems with binding in the opening and closing of a tainter gate, misalignment of equipment, the appearance of a pattern or map cracking, and the closing of some expansion joints. This behavior indicated movement, possibly due to volume change of the concrete. Since carbonate aggregate had been used in the concrete of this structure, there was concern over whether this volume change might have been caused by an expansive alkali-carbonate rock reaction. Therefore, examination and testing were recommended. Accordingly, published information about this reaction (1964 Symposium and Buck 1969, 1975) along with the Corps' present evaluation and control criteria (EM 1110-2-2000 1982) were consulted. The District requested petrographic examination of concrete from the structure to determine whether the field problems noted earlier were due to deleterious alkali-carbonate rock reaction or to one or more other recognizable causes.

Samples

4. Twenty-one 3-3/4-in.- diameter cores approximately 2 ft long were taken from the dam, galleries and adits, powerhouse, spillway piers, and

spray wall. Two 1-7/8-in.-diameter cores were taken from monoliths No. 7 and 15. These cores represented 219.6 ft and 244.9 ft of concrete, respectively. The cores also included some foundation rock. These cores were received 14 September 1983.

5. It could not be determined from examination and testing of the concrete whether deleterious alkali-carbonate rock reaction had occurred. Therefore, it was agreed by contact with the District that examination of rock from the abandoned quarry be included in an effort to answer this question. Accordingly, samples of rock were obtained and sent to the U.S. Army Engineer Waterways Experiment Station (WES) where they were received 13 July 1984. The concrete and rock samples were assigned Structures Laboratory (SL) serial numbers and described as follows:

SL Serial No.	Field Identification	
	Concrete Cores	
	Dam	
NASH-8 CON-1	AA 6-1	Vertical Boring
NASH-8 CON-2	AA 6-2	Vertical Boring
NASH-8 CON-3	AA 6-3	Vertical Boring
NASH-8 CON-4	AA 7-1	Vertical Boring
NASH-8 CON-5	AA 15-1	Vertical Boring
NASH-8 CON-6	AA 16-1	
NASH-8 CON-7	AA 16-2	
NASH-8 CON-8	AA 16-3	
NASH-8 CON-9	AA 17-1	
	Galleries	
NASH-8 CON-10	AA 5G	
NASH-8 CON-11	AA 12G	
NASH-8 CON-12	AA 16G	
NASH-8 CON-13	AA 17G	
	Powerhouse	
NASH-8 CON-14	AAU 2P	Horizontal Boring
NASH-8 CON-15	AAU 2D	Horizontal Boring
NASH-8 CON-16	AA 541	Vertical Boring
	Spillway	
NASH-8 CON-17	AA 7-2	Horizontal Boring
NASH-8 CON-18	AA 7-4	Horizontal Boring
NASH-8 CON-19	AA 7-5	Horizontal Boring
NASH-8 CON-20	AA 7-6	Horizontal Boring

SI Serial No.	Field Identification
	Spray Wall
NASH-8 CON-21	AL-LW
NASH-8 CON-22	MON-7
NASH-8 CON-23	MON-15
	Quarry Rock Samples
NASH-8 G-1	A-1
NASH-8 G-2	A-2
NASH-8 G-3	A-3
NASH-8 G-4	A-4
NASH-8 G-5	A-5
NASH-8 G-6	A-6
NASH-8 G-7	A-7
NASH-8 G-8	A-8
NASH-8 G-9	A-9
NASH-8 G-10	A-10
NASH-8 G-11	A-11
NASH-8 G-12	A-12
NASH-8 G-13	A-13
NASH-8 G-14	A-14
NASH-8 G-15	A-15
NASH-8 G-16	A-16
NASH-8 G-17	A-17
NASH-8 G-18	A-18
NASH-8 G-19	B-1
NASH-8 G-20	B-2
NASH-8 G-21	B-3
NASH-8 G-22	B-4
NASH-8 G-23	B-5
NASH-8 G-24	B-6
NASH-8 G-25	B-7
NASH-8 G-26	B-8
NASH-8 G-27	B-9
NASH-8 G-28	B-10
NASH-8 G-29	B-11
NASH-8 G-30	B-12
NASH-8 G-31	B-13
NASH-8 G-32	B-14
NASH-8 G-33	B-15
NASH-8 G-34	B-16
NASH-8 G-35	B-17
NASH-8 G-36	B-18
NASH-8 G-37	C-1
NASH-8 G-38	C-2
NASH-8 G-39	C-3
NASH-8 G-40	C-4
NASH-8 G-41	C-5
NASH-8 G-42	C-6

SL Serial No.	Field Identification
NASH-8 G-43	C-7
NASH-8 G-44	C-8
NASH-8 G-45	C-9
NASH-8 G-46	C-10
NASH-8 G-47	C-11
NASH-8 G-48	C-12
NASH-8 G-49	C-13
NASH-8 G-50	C-14
NASH-8 G-51	C-15
NASH-8 G-52	C-16
NASH-8 G-53	C-17
NASH-8 G-54	C-18
NASH-8 G-55	C-19
NASH-8 G-56	C-20
NASH-8 G-57	C-21
NASH-8 G-58	C-22
NASH-8 G-59	C-23
NASH-8 G-60	C-24
NASH-8 G-61	C-25
NASH-8 G-62	C-26
NASH-8 G-63	C-27
NASH-8 G-64	C-28
NASH-8 G-65	C-29
NASH-8 G-66	C-30

Each sample consisted of one piece of rock that was approximately 8 by 12 in. wide and long and about 6 to 8 in. thick.

Test procedure

6. Each of the 3-3/4-in. concrete cores was examined and logged at the laboratory. The NQ-size cores (NASH-8 CON-22 and 23) from monoliths 7 and 15 were logged in the field.

7. Selected pieces of core were taken for detailed examination and testing. Testing included removal of aggregate from the concrete by coring for testing according to CRD-C 146 (ASTM Designation: C 586) (USAEWES 1949).

8. The samples of rock from the quarry were all visually inspected. Each piece of rock was identified by rock type or variety, and specimens of each type were selected for petrographic examination. These specimens were selected from each of the series of rock (A, B, and C) as designated in the field.

9. Specimens were taken from selected samples and tested according to CRD-C 146 (USAEWES 1949).

10. Both the concrete cores and the quarry rock samples were examined petrographically to determine whether alkali-carbonate rock reaction had or

might occur. X-ray diffraction (XRD) patterns were made of selected rock samples to determine their mineralogical composition. Other concrete cores were sawed longitudinally; a surface was then ground and examined with a stereomicroscope. Carbonate aggregate particles with reaction rims were etched using dilute hydrochloric acid (HCl) (1 part HCl:4 parts distilled water) to provide information on the type of reaction rims present in the concrete.

11. Selected concrete cores were sawed to a 10-in. length, metal inserts were put into their ends, and the cores were tested for length change in an elevated temperature (100°F) in a moist room meeting the requirements of CRD-C 202 (ASTM C 511) (USAEWES 1949) to encourage chemical reaction. Initial reference lengths for the cores were obtained by immersing them in water for 21 days before the testing was started.

12. All XRD patterns were made using nickel-filtered copper radiation.

Results

13. The concrete was composed of crushed carbonate coarse and fine aggregate. The aggregate was of 3-1/2-in. nominal maximum size with much of the concrete examined containing aggregate apparently not exceeding 2-1/2-in. nominal maximum (Figures 1-21). The concrete from monolith 15 (core NASH-8 CON-23) was similar in appearance to that of the 21 other 3-3/4-in.-diameter concrete cores, but because of the mismatch between its 1-7/8-in.-diameter and maximum aggregate size (3-1/2-in.) plus excessive breakage of the concrete, no logs were prepared of either NQ-size core from monoliths 7 or 15. The core from monolith 7 was not examined since it was considered as unsuitable as the monolith 15 core.

14. The concrete was air entrained and generally appeared to be in good physical condition apart from longitudinal and transverse cracks that were observed. Some of the cracks were coated with debris and were open, indicating they were preexisting cracks. Some aggregate particles in fracture zones were coated with a white reaction product (photograph No. 1). This reaction product was identified as calcite and some alkali-silica reaction gel. The gel displayed characteristic drying shrinkage cracks when examined at high magnification with a stereomicroscope.

15. Small-diameter cores taken from aggregate particles in concrete cores NASH-8 CON-9, 13, and 14 were tested for expansion according to CRD-C 146 (USAEWES 1949) for 1 year. Rock cores from concrete core NASH-8 CON-9

expanded to more than 0.2 percent (Table I and Figure 22) indicating that the aggregate was potentially reactive using the criteria of the Corps of Engineers (1982). The specimens that were obtained for this testing were necessarily shorter than test requirements. Rock cores taken from rock from the abandoned quarry were obtained and tested in an effort to verify these expansions.

16. The majority of the rock from the quarry was fine-grained to lithographic carbonate rock. Some of the rock samples appeared massively bedded while others were thinner bedded. Some were transitional in texture within one piece. The rock was generally olive black (5 Y 2/1) or olive gray (5 Y 4/1) (Goddard 1975). Some rock particles were mottled and fossiliferous.

17. Of the 66 rock samples received, 18 were selected for expansion testing. Those selected are shown below:

SL Rock Serial No.	Field Identification	Variety of Carbonate Rock
NASH-8 G-1	A-1	Lithographic, olive gray
NASH-8 G-9	A-9	*
NASH-8 G-10	A-10	Lithographic, olive black
NASH-8 G-14	A-14	Coarse grained, brownish gray
NASH-8 G-18	A-18	Lithographic, olive black
NASH-8 G-19	B-1	Coarse grained, olive gray
NASH-8 G-20	B-2	Lithographic, olive gray
NASH-8 G-22	B-4	Weathered, dark yellowish brown, dolomite
NASH-8 G-24	B-6	Dark yellowish brown
NASH-8 G-29	B-11	Lithographic, olive black
NASH-8 G-35	B-17	Lithographic, brownish black
NASH-8 G-39	C-3	Lithographic, olive black
NASH-8 G-45	C-9	Lithographic, olive black
NASH-8 G-48	C-12	Mottled, olive gray
NASH-8 G-52	C-16	Lithographic, light olive gray
NASH-8 G-56	C-20	Lithographic, brownish black
NASH-8 G-58	C-22	Coarse grained, olive gray
NASH-8 G-64	C-28	Lithographic, olive black

* Selected for test but could not obtain long enough core due to lack of adequate bedding thickness.

18. Testing of these rock cores to 140 days indicated that most of the rock tested was expansive enough to be classified as potentially reactive. A few cores indicated potentially reactive rock (Table II and Figure 23) by the criteria of the Corps of Engineers (1982). Specimens made from NASH-8 G-48 and G-52 expanded 0.228 and 0.225 percent, respectively, during the testing period.

19. Concrete cores tested at elevated temperature and high relative humidity did not expand appreciably during the test period. The maximum expansion was 0.02 percent for 1 year of testing (Table III and Figure 23).

20. The aggregate used in the concrete at Center Hill Dam was a fine-grained to lithographic dolomitic limestone. According to Buck (1969), such rock could be reactive and should be evaluated by CRD-C 146. The mineralogical composition for much of the rock was calcite with some dolomite and quartz. Some of the aggregate particles also contained clays and feldspars (Table IV).

21. The concrete contains many aggregate particles with reaction rims (photograph No. 2). When these carbonate particles were acid etched, the rims were less soluble and were left in relief.

Discussion

22. Some of the carbonate aggregate used in the construction of Center Hill Dam was reactive as indicated by expansion of aggregate from the concrete and of rock from the quarry that supplied aggregate for the project. The amount and location of the reactive aggregate in the quarry could be determined based on sample location, but this was not done. Reactivity was also indicated by the presence of recognizable reaction rims on crushed carbonate aggregate particles in the concrete.

23. No information on the alkali content of the project cements was obtained. It is likely that some high alkali-cement was used. This is based on the presence of some alkali-silica gel indicating that alkali-silica reaction has occurred plus the reaction rims on many of the coarse aggregate particles. The reaction rims were produced in the portland-cement concrete since crushed stone cannot develop weathering rims prior to use as aggregate.

24. The concrete tested did not expand at elevated temperatures and humidity. This may indicate that the reaction may have already gone to completion, that the reaction in the concrete takes place more slowly than expected even under accelerating conditions, or that the concrete tested included no reactive material.

25. The lack of concrete expansion in the laboratory does not indicate that concrete in other parts of the structure is not reactive. The Penn-Dixie cement from Richard City, Tennessee, has a history of associated alkali-carbonate rock reaction at Chickamauga Dam Powerhouse (Luke 1963, 1964). This suggests the possibility that local concentrations of reactive aggregate

combined with high-alkali cement were sufficient to cause some concrete to expand and crack in those areas where the environmental conditions and materials combinations are appropriate to promote an alkali-carbonate rock reaction. This also suggests that the uniformity of the concrete throughout the structure may vary because of the use of cements from two mills and aggregate from ledges of differing degrees of reactivity. It would be difficult to isolate reactive and nonreactive zones in the structure at this time.

Conclusion

26. It is concluded that all or part of the cracking in this structure is due to deleterious alkali-carbonate rock reaction.

27. Factors used in reaching this conclusion include:

- a. Field observations indicative of increase in volume of concrete.
- b. The presence of old cracks in the cores.
- c. Evidence of alkali-carbonate rock reaction as reaction rims on aggregate particles in the concrete.
- d. Expansion of some carbonate rock from the concrete and from the abandoned quarry site that indicates a potential for deleterious alkali-carbonate rock reaction.
- e. Lack of evidence of other factors known to cause cracking of concrete. The small amount of evidence of alkali-silica reaction that was found was not considered significant as a cause of cracking of the structure.

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Table 1

Center Hill Length Change (% Expansion)

Length Change Data (CRD C-146)

Age, (Days)	NASH-8 CON-9 PC-A	NASH-8 CON-13 PC-A	NASH-8 CON-14 PC-A	NASH-8 CON-14 PC-B	NASH-8 CON-14 PC-C
7	.000	-.074	-.004	.000	-.006
14	.005	-.074	.000	.008	-.004
21	.005	-.070	.000	.012	-.004
28	.004	-.064	-.011	.013	-.007
56	.030	-.021	-.014	.020	-.010
84	.052	-.007	-.011	.041	-.010
112	.102	-.027	-.011	.055	-.013
140	.143	.007	-.007	.084	-.004
168	.165	.007	.011	.088	-.004
196	.196	.007	.007	.092	-.003
224	.196	.024	.007	.108	-.003
252	.205	.011	.007	.093	.000
280	.205	.011	.007	.097	.000
308	.205	.011	.007	.100	.000
336	.205	.011	.007	.100	.000
364	.209	.011	.007	.100	.000

Table 2

Center Hill Length Change (% Expansion)

Length Change (CRD C-146)

Age, Days	NASH-8 G-1	NASH-8 G-9*	NASH-8 G-10	NASH-8 G-14	NASH-8 G-18	NASH-8 G-19	NASH-8 G-20	NASH-8 G-22	NASH-8 G-24
7	.004		.000	.000	.003	.000	.003	.000	.000
14	.004		.000	.000	.003	.000	.003	.003	.000
21	.004		.000	.000	.003	.000	.003	.004	.000
28	.004		.000	.000	.003	.004	.003	.004	.000
56	.004		.000	.000	.003	.004	.003	.004	.000
84	.004		.000	.000	.003	.004	.003	.004	.000
112	.004		.000	.000	.003	.004	.003	.004	.000
140	.004		.000	.000	.003	.004	.003	.004	.000

Age, Days	NASH-8 G-29	NASH-8 G-35	NASH-8 G-39	NASH-8 G-45	NASH-8 G-48	NASH-8 G-52	NASH-8 G-56	NASH-8 G-58	NASH-8 G-64
7	.000	.000	.007	.000	.029	.027	.007	.000	.000
14	.000	.000	.004	.000	.029	.060	.007	.000	.000
21	.004	.000	.011	.000	.090	.126	.011	.000	.000
28	.004	.000	.024	.017	.080	.133	.014	.000	.000
56	.004	.000	.035	.017	.109	.139	.014	.000	.000
84	.004	.000	.035	.017	.145	.153	.014	.000	.000
112	.004	.000	.045	.017	.177	.182	.014	.000	.000
140	.004	.000	.058	.017	.228	.225	.014	.000	.000

* Unable to obtain cores for these pieces.

Table 3

Length Change of Concrete Cores, %

	CORE NO.						
	NASH-8 CON-22			NASH-8 CON-23			
Age, Days	47.6-48.3 ft	54.5-55.1 ft	55.2-56.0 ft	4.5-5.9 ft	95.2-96.05 ft	115.5-116.45 ft	210.9-211.8 ft
1							
7							
14							
21*	0	0	0	0	0	0	0
28	0.01	0.01	0.01	0	0	-0.01	0
56 (2 months)**	0.01	0.01	0.01	0	0	0	0
84 (3 months)	0.02	0.01	0.01	0	0.01	-0.01	0
112 (4 months)	0.02	0.01	0.01	0.01	0.01	-0.01	0
140 (5 months)	0.02	0.01	0.01	0.01	0.01	-0.01	-0.01
168 (6 months)	0.02	0.01	0.01	0.02	0.01	-0.01	0
196 (7 months)	0.02	0.01	0.02	0.01	0.02	-0.01	0
224 (8 months)				0.02	0.02	-0.01	0
252 (9 months)				0.01	0.03	-0.01	0
280 (10 months)				0.01	0.03	-0.01	0
308 (11 months)				0.01	0.03	-0.01	0
336				0.01	0.03	-0.01	0
364 (12 months)				0.01	0.03	-0.01	0
14 months				0.02	0.04	0.01	0

* 21-days age is the reference length for all cores. All lengths are compared to this.

** Ages in parentheses are for cores from NASH-1 CON-22.

Table 4

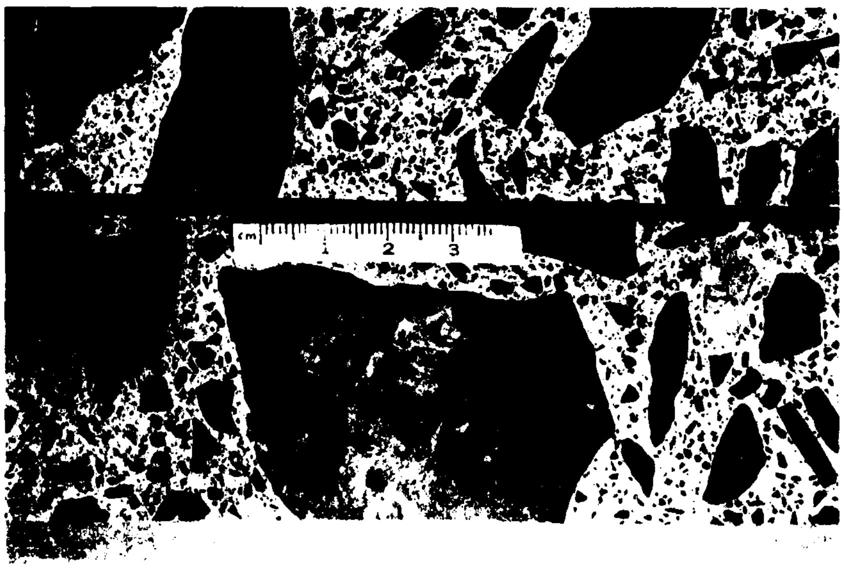
Mineral Constituents of Aggregates

Center Hill Dam (X-Ray Diffraction)

Mineral constituent	CON-3 A	CON-3 B	CON-10 A	CON-10 B	CON-13 A	CON-14 A	CON-14 B	CON-14 C	CON-18 A-1	CON-18 A-2	CON-21 A	CON-21 B	CON-21 C	CON-9 PCA
calcite	C	A	I	A	I	A	A	A	A	A	I	A	A	A
dolomite	C	I	C	-	M	-	I	C	C	M	I	-	M	I
quartz	I	M	C	C	I	C	C	I	C	M	C	C	C	C
plagioclase feldspar	M	-	M	-	M	-	-	C	M	M	M	M	M	-
potassium feldspar	M	-	-	-	R	-	-	-	-	-	-	-	-	-
chlorite	M	-	-	-	-	-	-	-	-	-	-	-	-	-
kaolinite	M	-	R	-	-	-	-	-	-	-	-	-	R	-
clay-mica	C	-	R	-	-	-	-	-	M	-	R	-	M	-
misc	R	-	-	-	-	-	-	-	-	-	-	-	R	-
14 Å	-	-	R	-	-	-	-	-	-	-	-	-	-	-

A = Abundant
I = Intermediate
C = Common
M = Miner
R = Rare

Photograph 1. Fractured concrete surface showing white reaction product around aggregate particle.

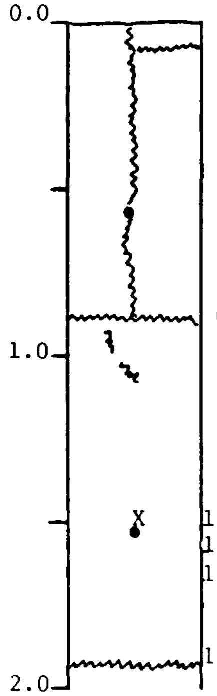


Photograph 2. Center Hill Dam concrete (core NASH-8 CON-23) with bottom piece from 0.9-ft to 1.55-ft depth and top piece from 210.3-ft to 210.9-ft depth. Reaction rims are readily visible on these ground surfaces. Magnification 0.9X

Center Hill Dam, Nashville, Tennessee
3-3/4-in.-diameter concrete cores from dam

NASH-8 CON-1 (AA6-1)

Depth, ft



Finished surface

0.1 ft - old crack

2-1/2-in. nominal maximum size carbonate coarse and fine ag

0.6 ft - Old crack 1/4-in.-diam heavily rusted reinforcing steel

0.8 ft-old crack

air entrained good consolidation, no segregation, concrete appears in good condition

1.1 ft incipient crack

1.4-ft-reaction product looks like alkali-silica gel
1-in. reinforcing steel

reaction rims prominent

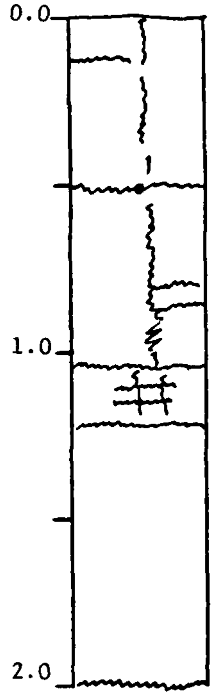
1.9

Figure 1

Center Hill Dam, Nashville, Tennessee
3-3/4-in.-diameter concrete cores from dam

NASH-8 CON-2 (AA6-2)

Depth, ft



Finished surface, slightly eroded

0.2 ft

vertical crack, coated

0.5-ft-old, slightly rusted 2 pcs 1/4-in. reinforcing steel

2-1/2-in. nominal maximum size carbonate coarse and fine aggregate

1.1 ft-fractured old crack

1.3 ft-old slightly coated crack

air entrained, good consolidation, no segregation

2.0 ft

White deposits on aggregate (appear to be alkali-silica gel), some reaction rims on aggregate particles

Figure 2

Center Hill Dam, Nashville, Tennessee
3-3/4-in.-diameter concrete cores from dam

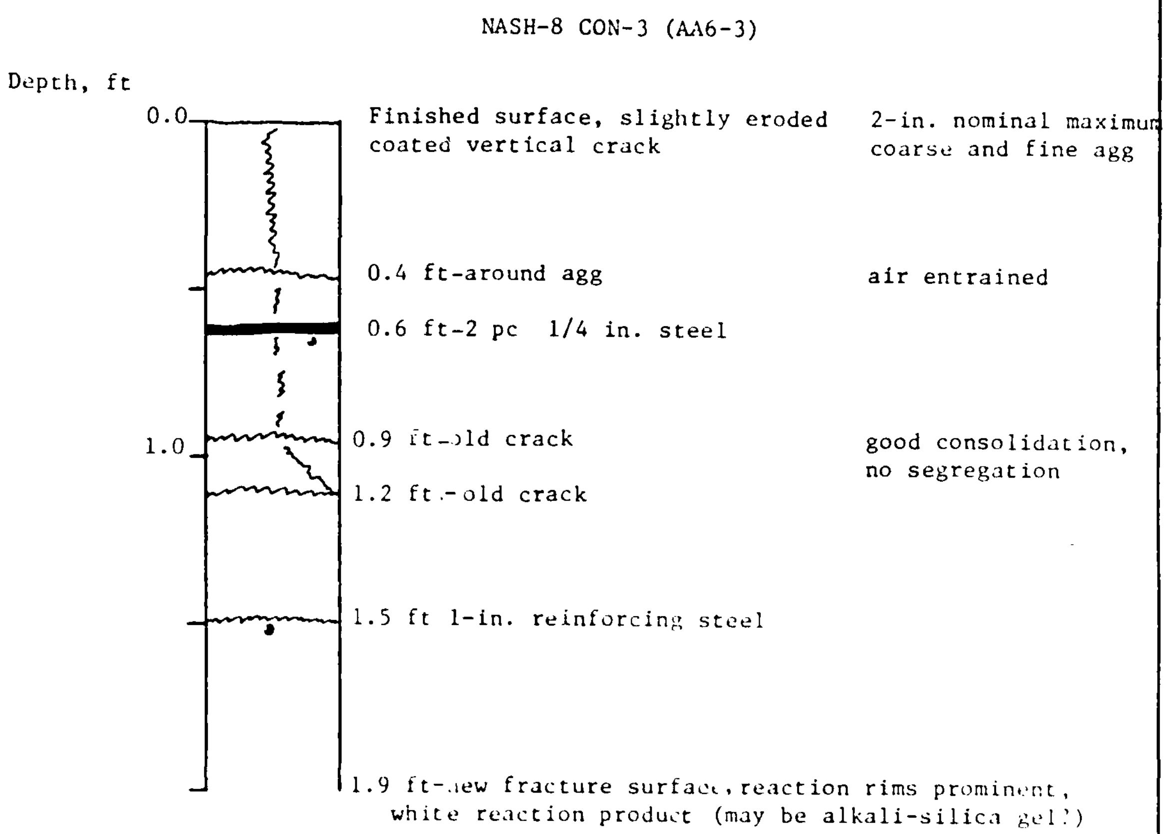
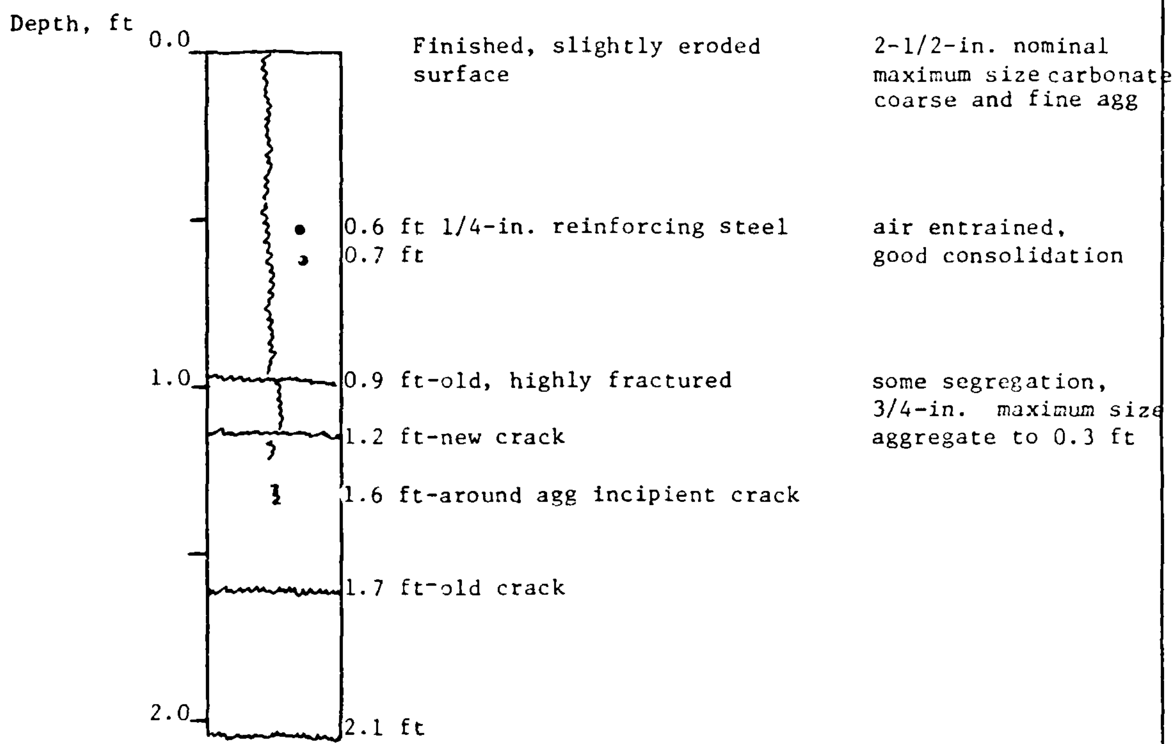


Figure 3

Center Hill Dam, Nashville, Tennessee
3-3/4-in.-diameter concrete cores from dam

NASH-1 CON-4 (AA7-1)

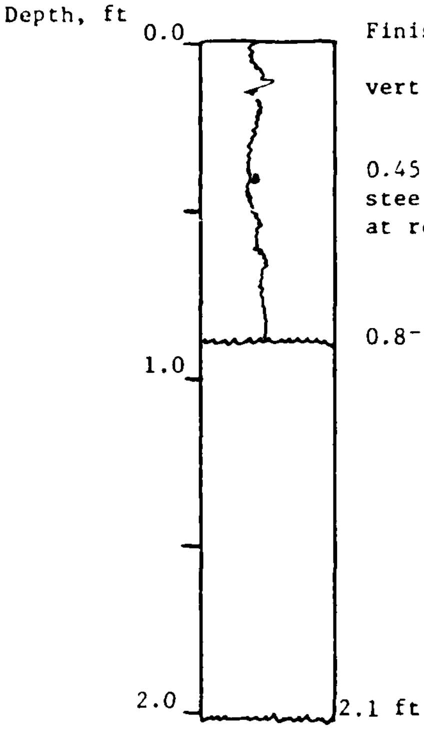


Some reaction rims, not prominent

Figure 4

Center Hill Dam, Nashville, Tennessee
3-3/4-in.-diameter concrete cores from dam

NASH-8 CON-5 (AA15-1)



Finished, slightly eroded surface

vertical crack open 1/16 in.

0.45 ft-(1/4-in. reinforcing steel) vertical crack closed at reinforcing steel

0.8-ft cold joint

2-in. nominal maximum size carbonate coarse and fine agg air entrained, good consolidation, no segregation

some reaction rims

Figure 5

Center Hill Dam, Nashville, Tennessee
3-3/4-in.-diameter concrete cores from dam

NASH-8 CON-6 (AA 16-1)

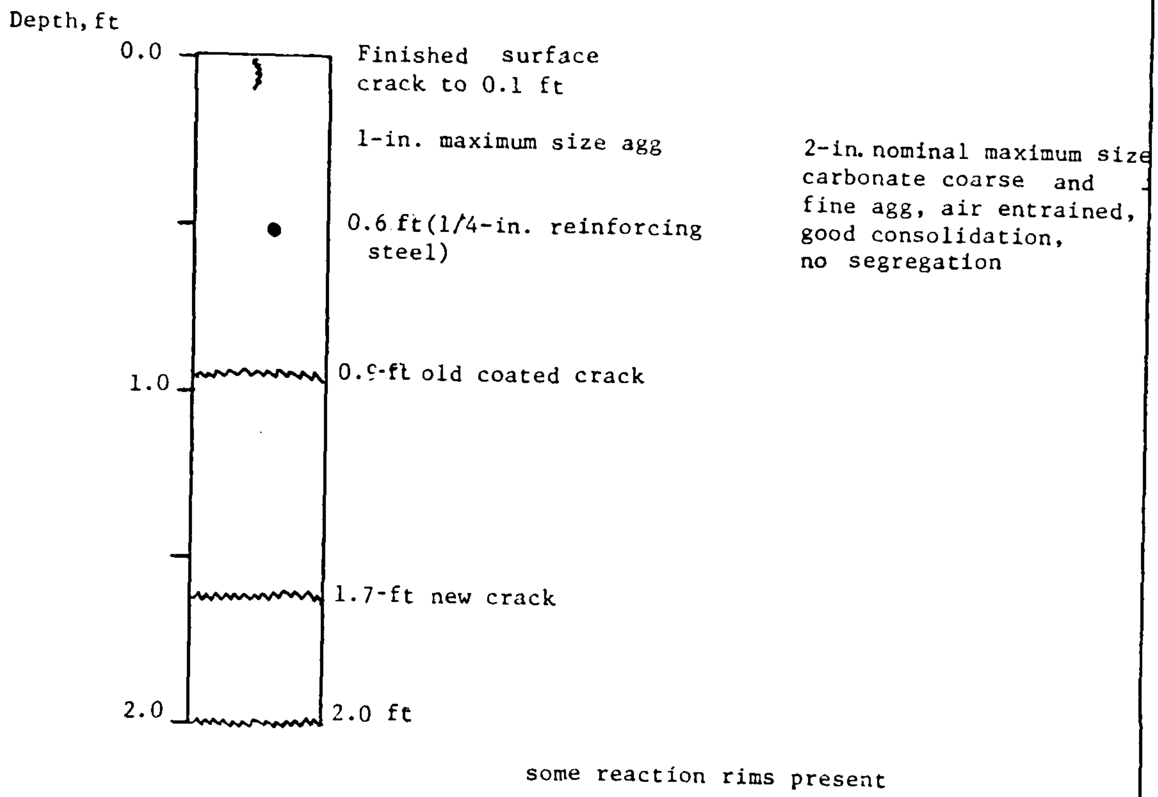


Figure 6

Center Hill Dam, Nashville, Tennessee
3-3/4-in.-diameter concrete cores from dam

NASH- 8 CON-7 (AA 16-2)

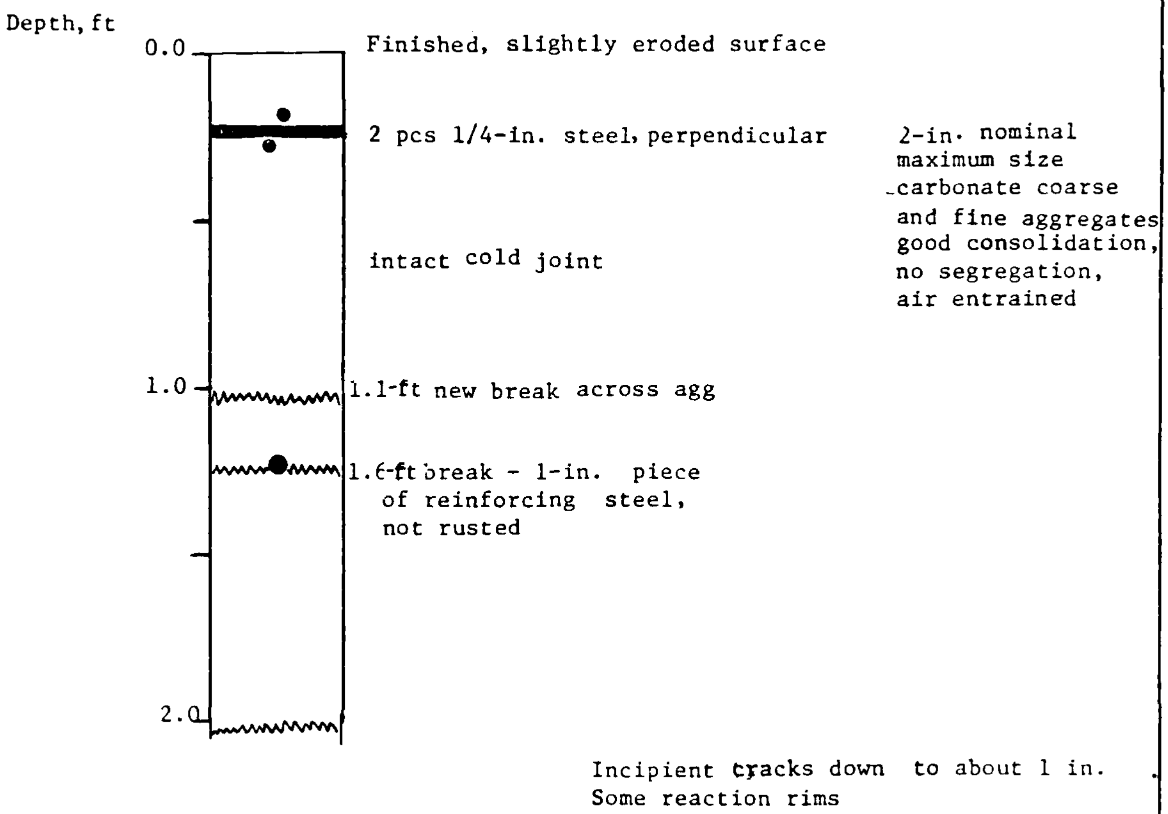


Figure 7

Center Hill Dam, Nashville, Tennessee
3-3/4-in diameter concrete cores from dam

NASH-8 CON-8 (AA 16-3)

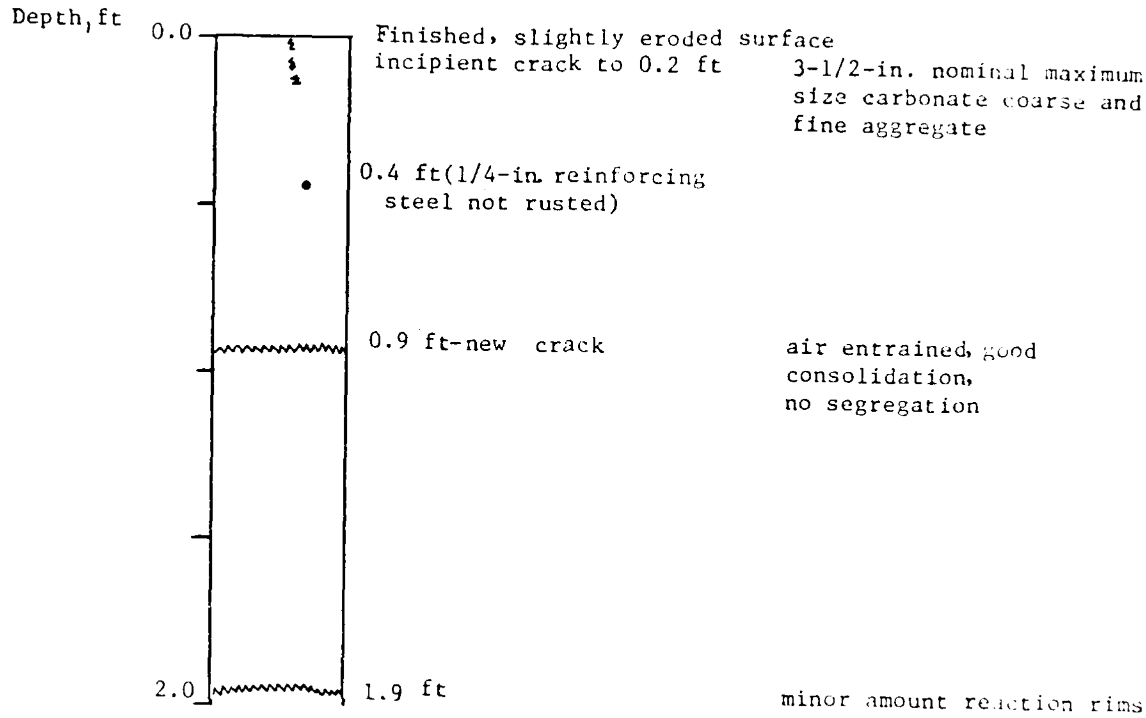
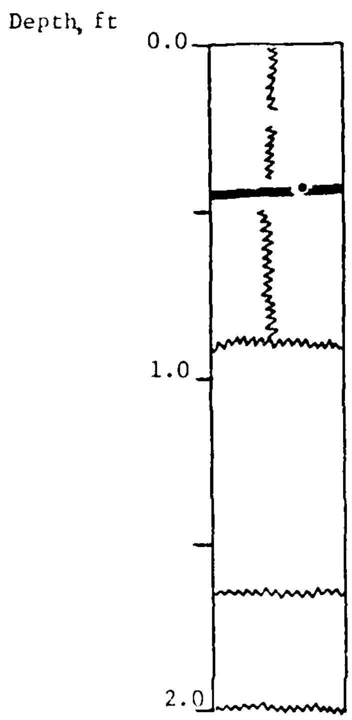


Figure 8

Center Hill Dam, Nashville, Tennessee
3-3/4-in.-diameter concrete cores from dam

NASH-8 CON-9 (AA 17-1)



Finished slightly eroded surface

vertical crack open 1/16 in.

0.4 ft - 2 pc 1/4-in. reinforcing steel

0.8 - ft old coated crack

1.7-ft new crack

3-1/2-in. nominal maximum size carbonate coarse and fine aggregate

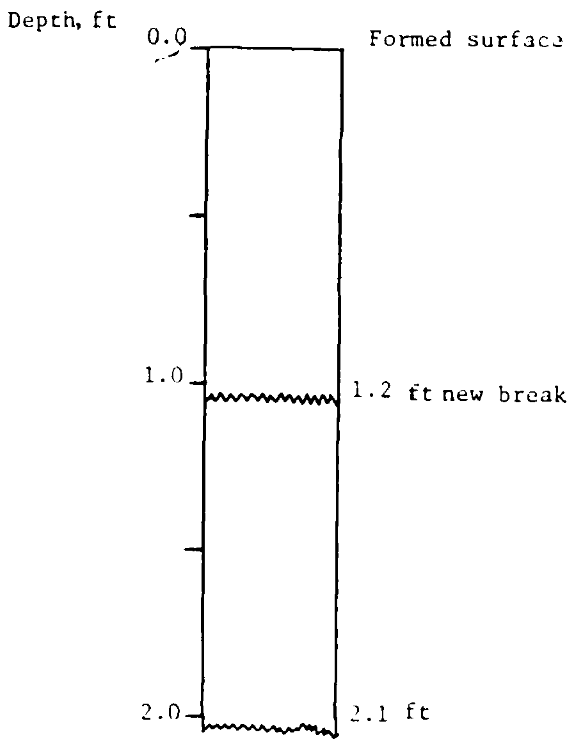
air entrained, good consolidation, no segregation

some reaction rims observed

Figure 9

Center Hill Dam, Nashville, Tennessee
3-3/4-in.-diameter concrete cores from gallery

NASH-8 CON-10 (AASG)



2-1/2-in.nominal maximum size carbonate coarse and fine agg

good consolidation no segregation, air entrained

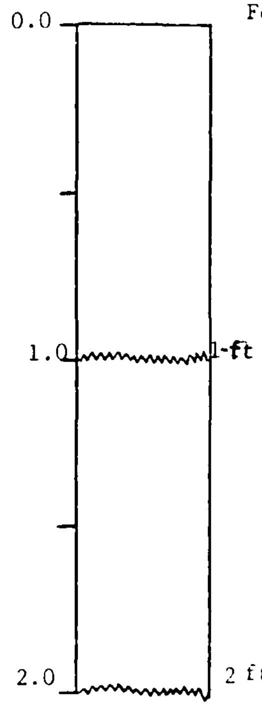
very minor reaction rims

Figure 10

Center Hill Dam, Nashville, Tennessee
3-3/4-in. - diameter concrete cores from gallery

NASH- 8 CON-11 (AA 12G)

Depth, ft



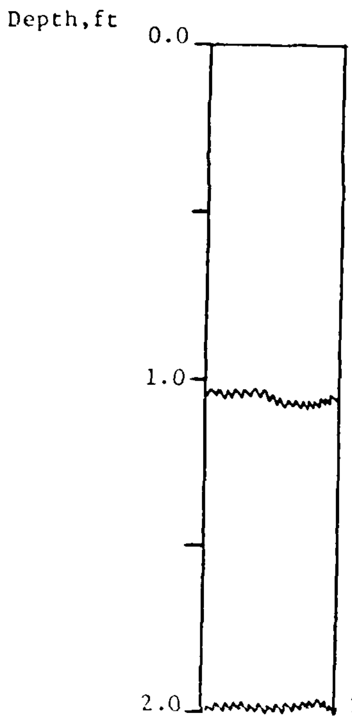
Formed surface

2-in. nominal maximum size carbonate coarse and fine agg, air entrained, good consolidation, no some reaction rims

Figure 11

Center Hill Dam, Nashville, Tennessee
3-3/4-in.-diameter concrete cores from gallery

NASH-8 CON-12 (AA 16G)



Finished surface, stained

3-in. nominal maximum size carbonate coarse and fine agg

12 ft-new crack

some 1/4-in. and larger vugs, no segregation, air entrained

2 ft void filled with white reaction product (alkali silica gel?)

some reaction rims

Figure 12

Center Hill Dam, Nashville, Tennessee
3-3/4-in.-diameter concrete cores from gallery

NASH-8 CON-13 (AA 17G)

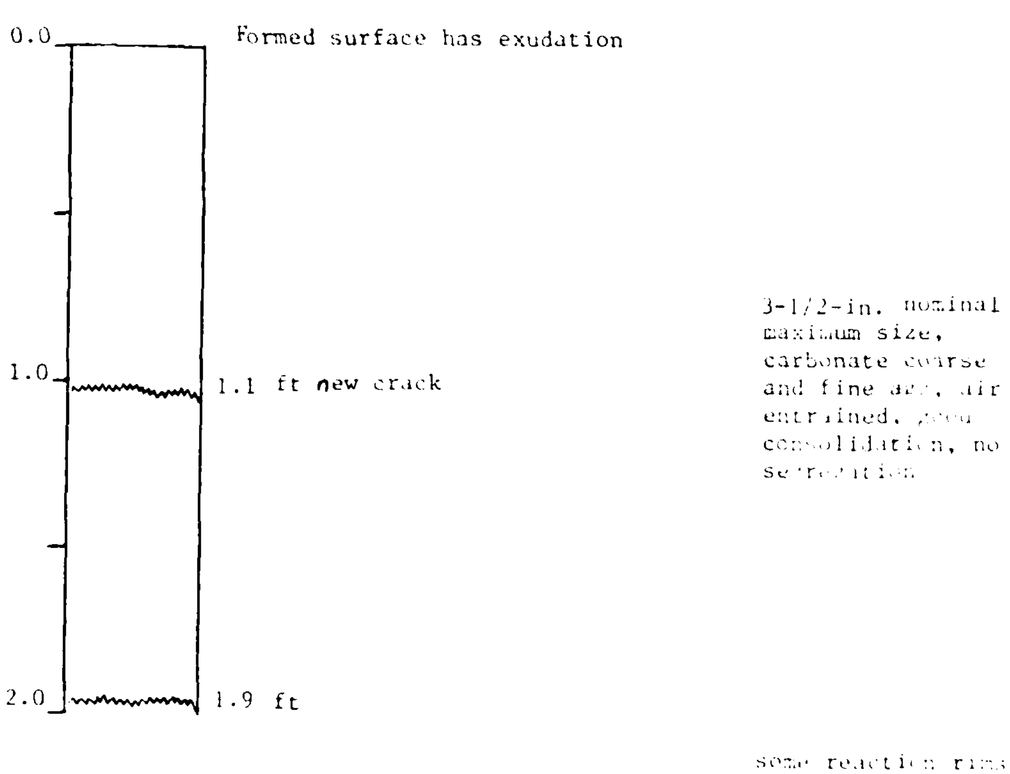
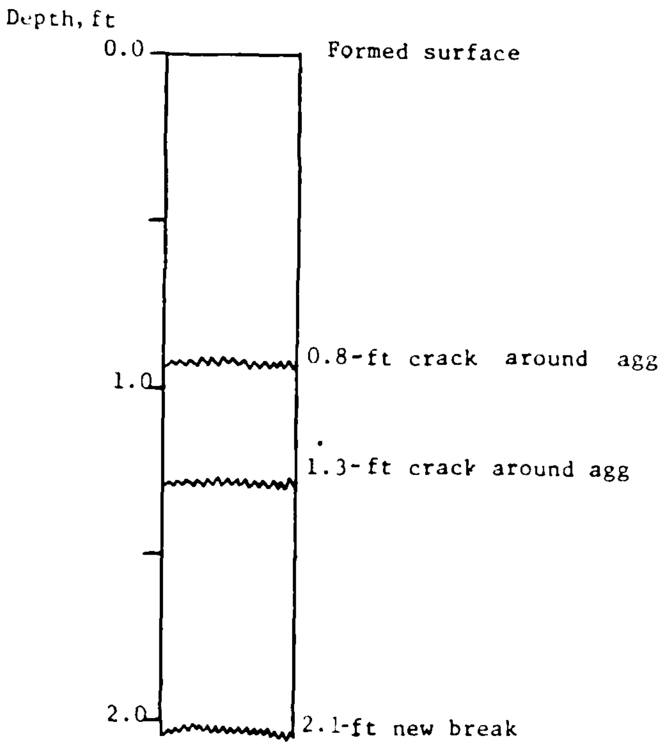


Figure 13

Center Hill Dam, Nashville, Tennessee
3-3/4-in.-diameter concrete cores from powerhouse

NASH-8 CON-14 (AAU2 P)



some incipient surface cracking

2-in. nominal maximum size carbonate coarse and fine agg, good consolidation, no segregation, air entrained

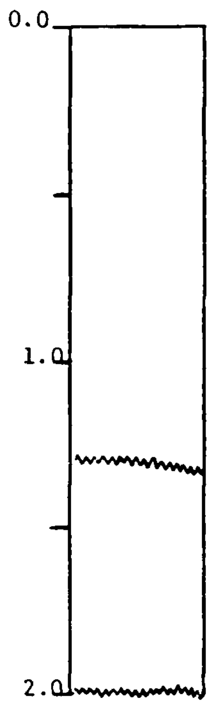
no apparent reaction rims

Figure 14

Center Hill Dam, Nashville, Tennessee
3-3/4-in.-diamater concrete c~..s from powerhouse

NASH-8 CON-15 (AAU2 D)

Depth, ft



Painted formed surface

3-1/2-in. nominal maximum size carbonate coarse and fine agg

1.3-ft new crack mainly through agg

air entrained, good consolidation, no segregation

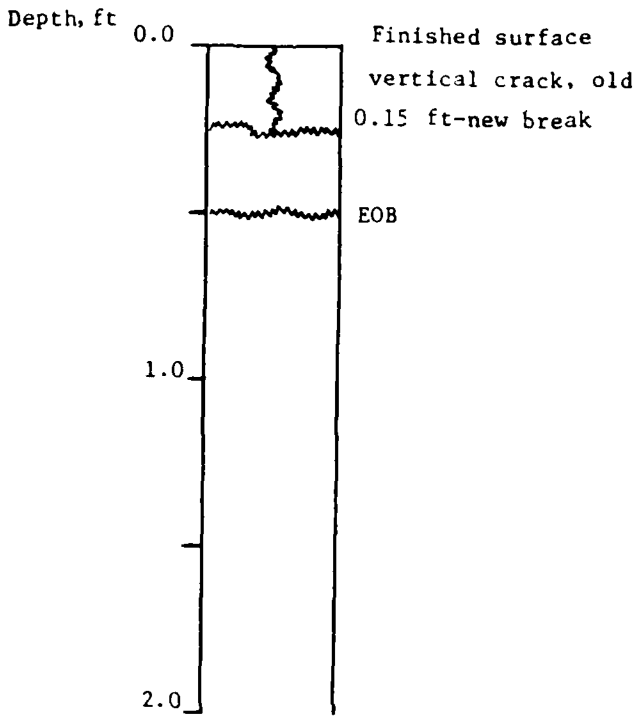
2.0 ft

Reaction minimal; may have a few reaction rims, concrete in good condition

Figure 15

Center Hill Dam, Nashville, Tennessee
3-3/4-in.-diameter concrete cores from powerhouse

NASH-8 CON-16 (AA-541)



Two types concrete, top is 1/4-in. nominal maximum size carbonate coarse and fine agg, air entrained, good consolidation, no segregation

Bottom 3/4-in. nominal maximum size carbonate coarse and fine agg, air entrained, good consolidation, no segregation, some reaction rims

Figure 16

Center Hill Dam, Nashville, Tennessee
3-3/4-in.-diameter concrete cores from spillway

NASH-8 CON-17 (AA 7-2)

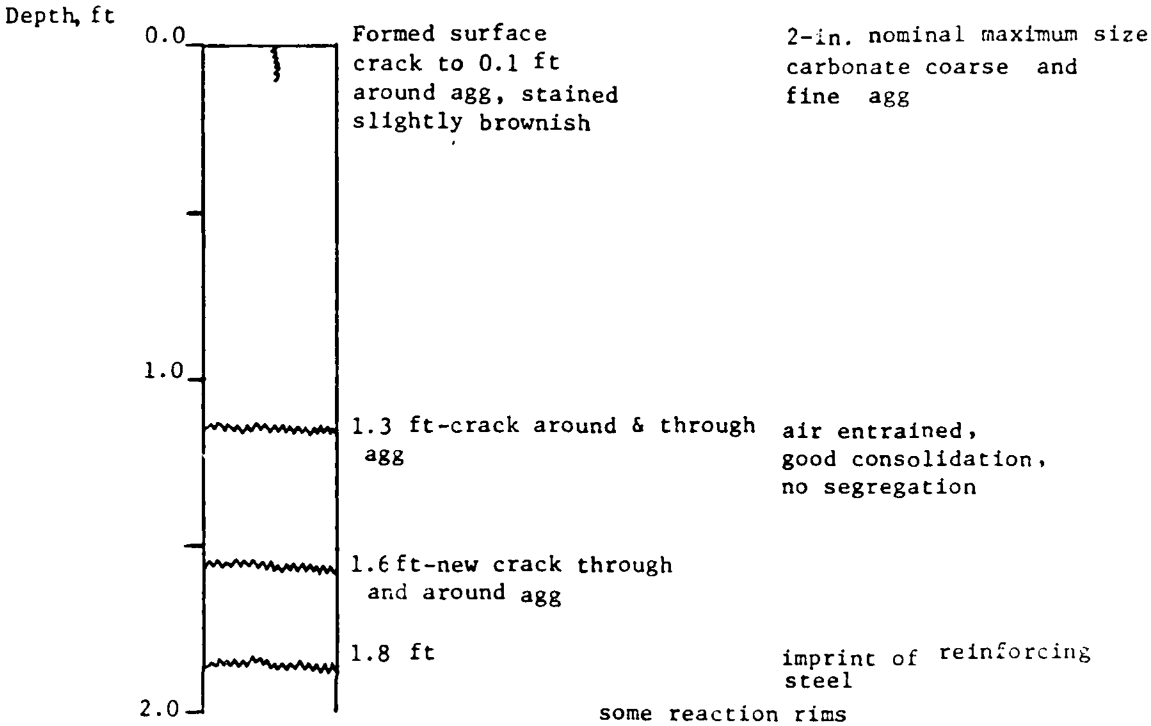
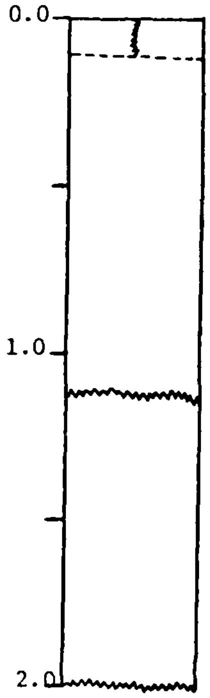


Figure 17

Center Hill Dam, Nashville, Tennessee
3-3/4-in.-diameter concrete cores from spillway

NASH-8 CON-18 (AA7-4)

Depth, ft



Formed surface

0.1 ft-deep crack tends to go around agg (light color paste)

2-1/2-in. nominal maximum size carbonate coarse and fine agg, air entrained, good consolidation, no segregation

1.2 ft crack around agg

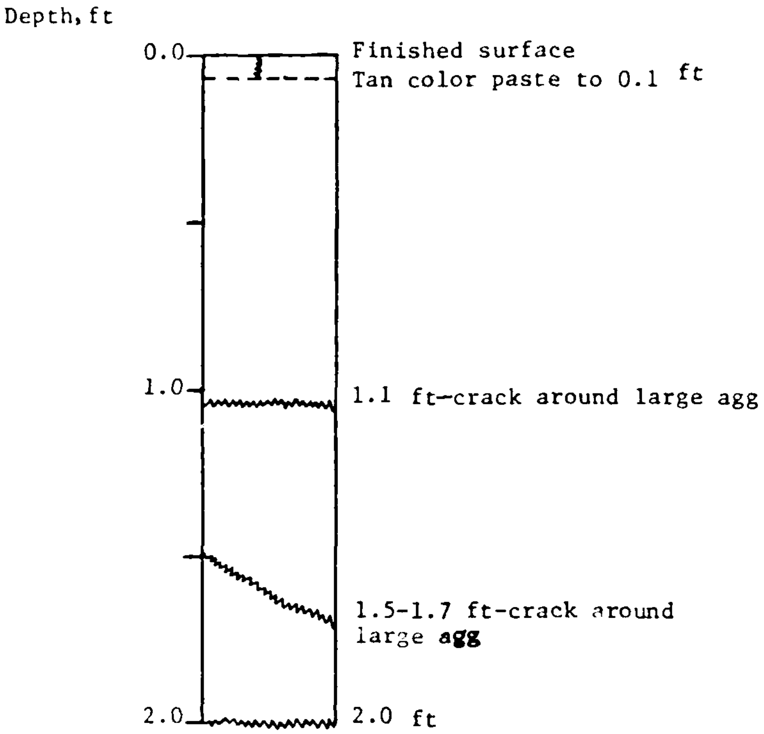
2.0 ft EOB

Several particles with reaction rims in lighter colored aggregates. In general, concrete looks in good condition

Figure 18

Center Hill Dam, Nashville, Tennessee
3-3/4-in.-diameter concrete cores from spillway

NASH-8 CON-19 (AA7-5)



2-in. nominal maximum size carbonate coarse and fine aggregate, air entrained, good consolidation, no segregation

Some reaction rims on aggregate particles

Figure 19

Center Hill Dam, Nashville, Tennessee
3-3/4-in.—diameter concrete cores from spillway

NASH-8 CON-20 (AA 7-6)

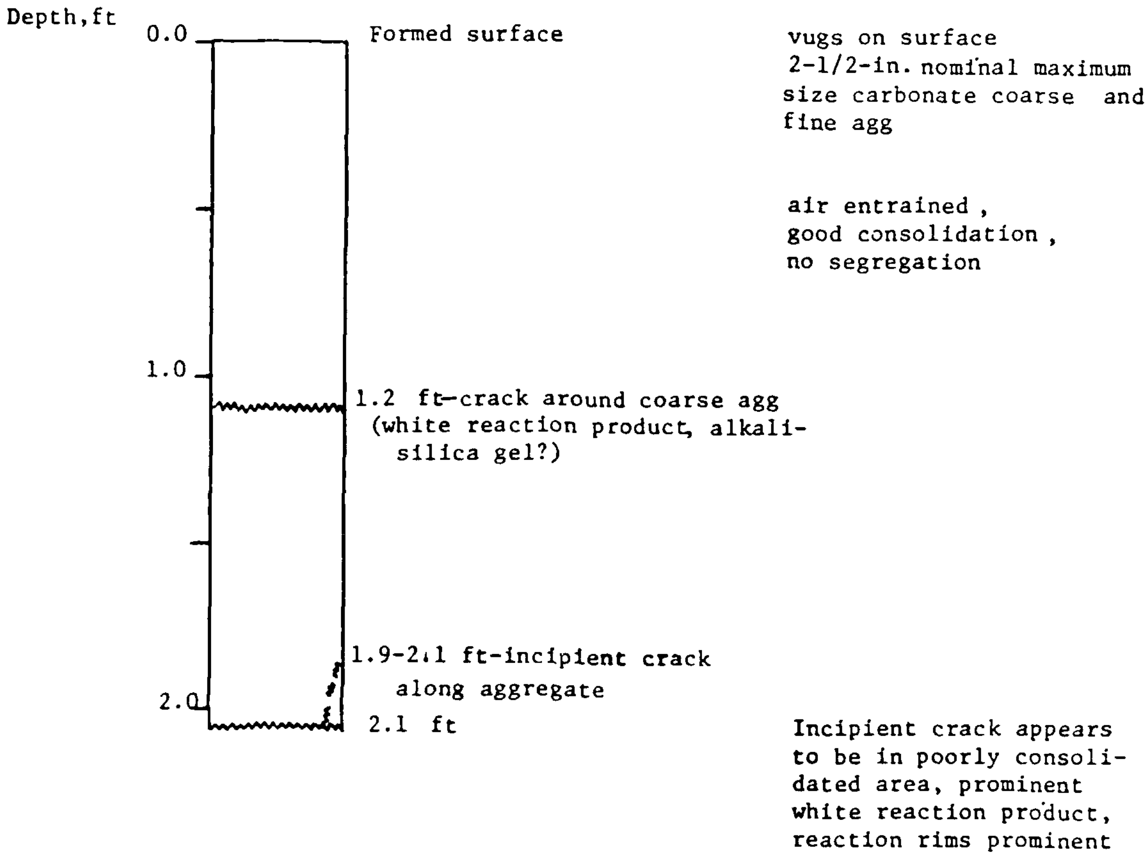
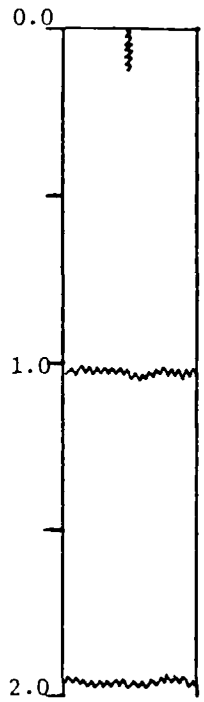


Figure 20

Center Hill Dam, Nashville, Tennessee
3-3/4-in.-diameter concrete cores from spray wall

NASH- 8 CON-21 (AA-LW)

Depth, ft



Formed surface - hairline crack across top
slight exudation, incipient crack down to 1-1/2 in.

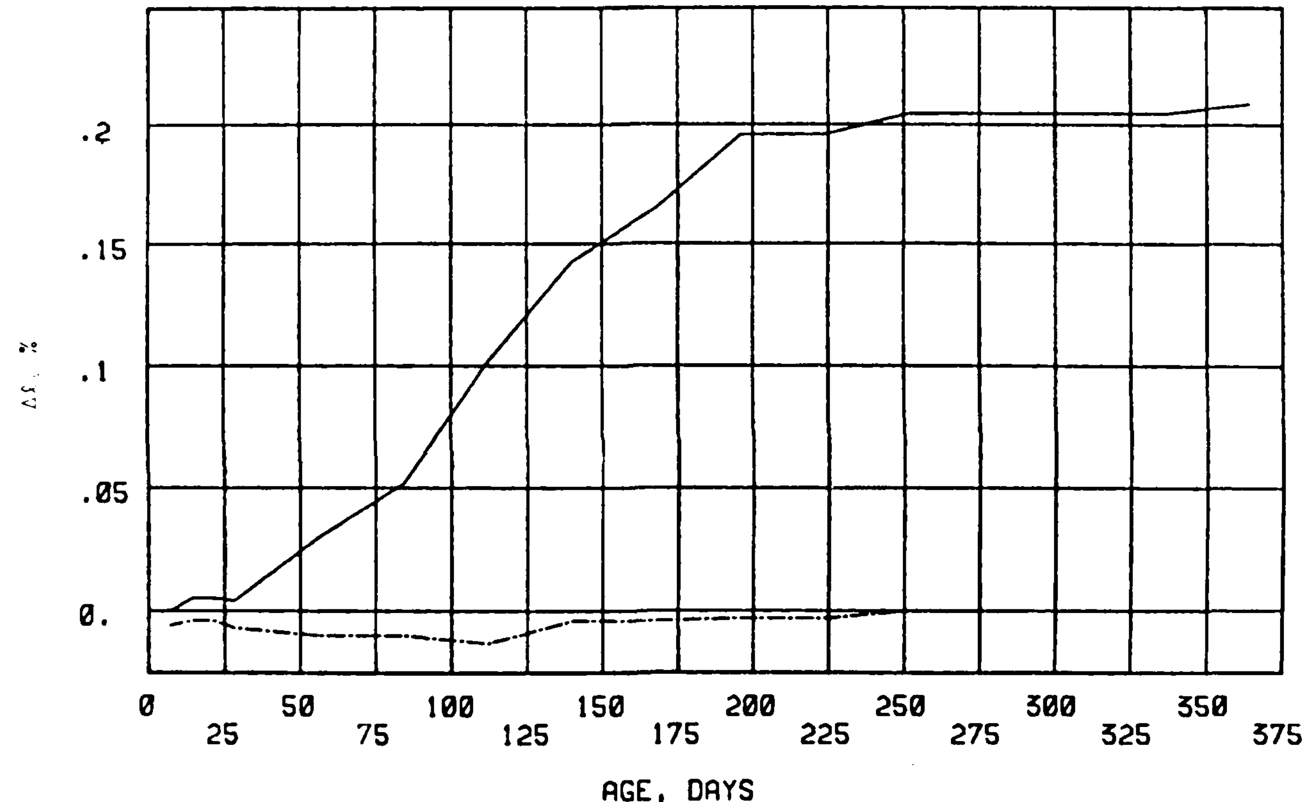
1-in. nominal maximum size carbonate coarse and fine agg, air entrained, good consolidation, no segregation

1.2 ft-new crack

1.9 ft

some reaction rims

Figure 21



EXPANSION OF ROCK CYLINDERS
FROM CONCRETE AGGREGATE
CENTER HILL DAM

Figure 22

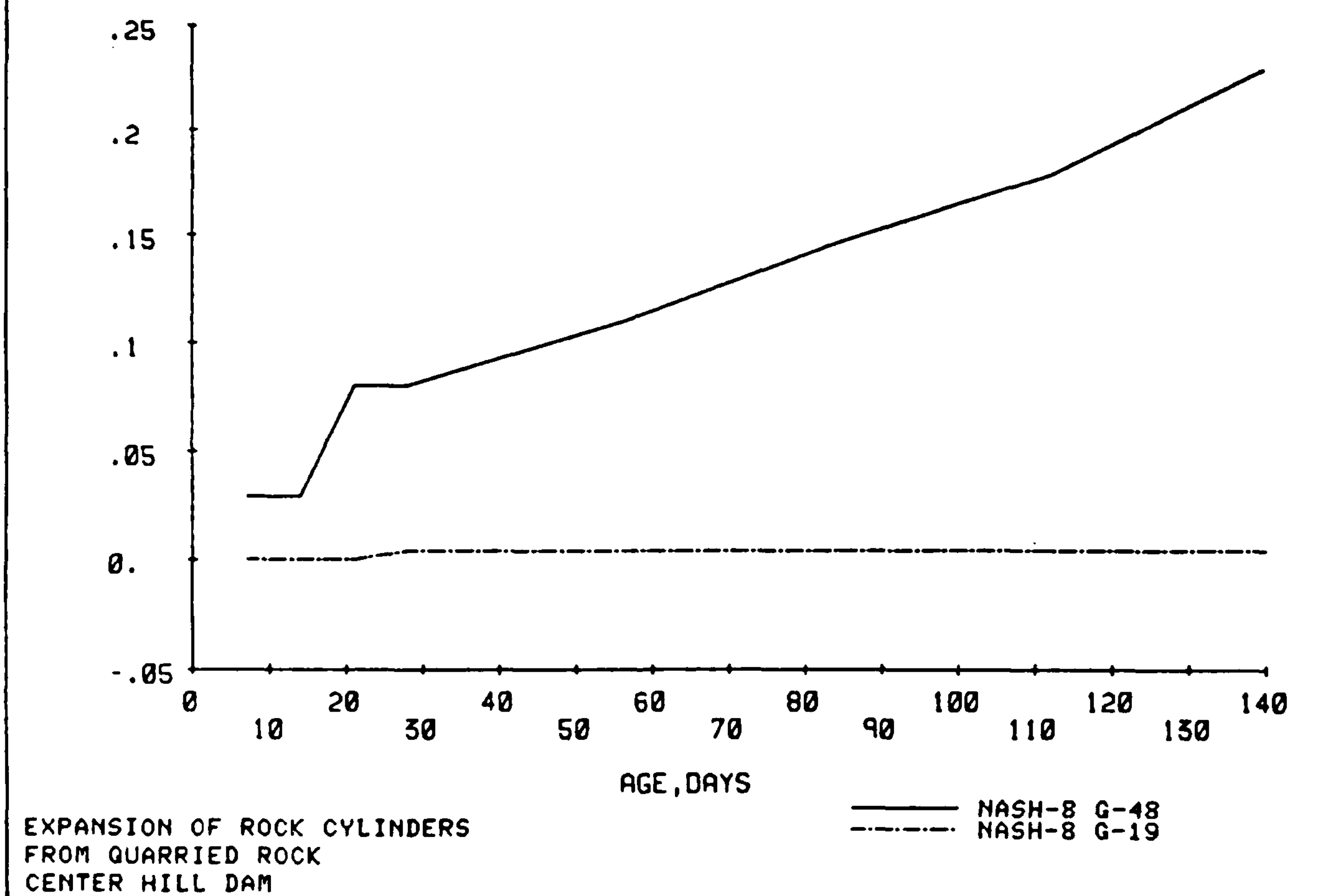

.25
.2
.15
.1
.05
0.
-.05
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
AGE, DAYS
NASH-8 G-48
NASH-8 G-19
EXPANSION OF ROCK CYLINDERS
FROM QUARRIED ROCK
CENTER HILL DAM

Figure 23

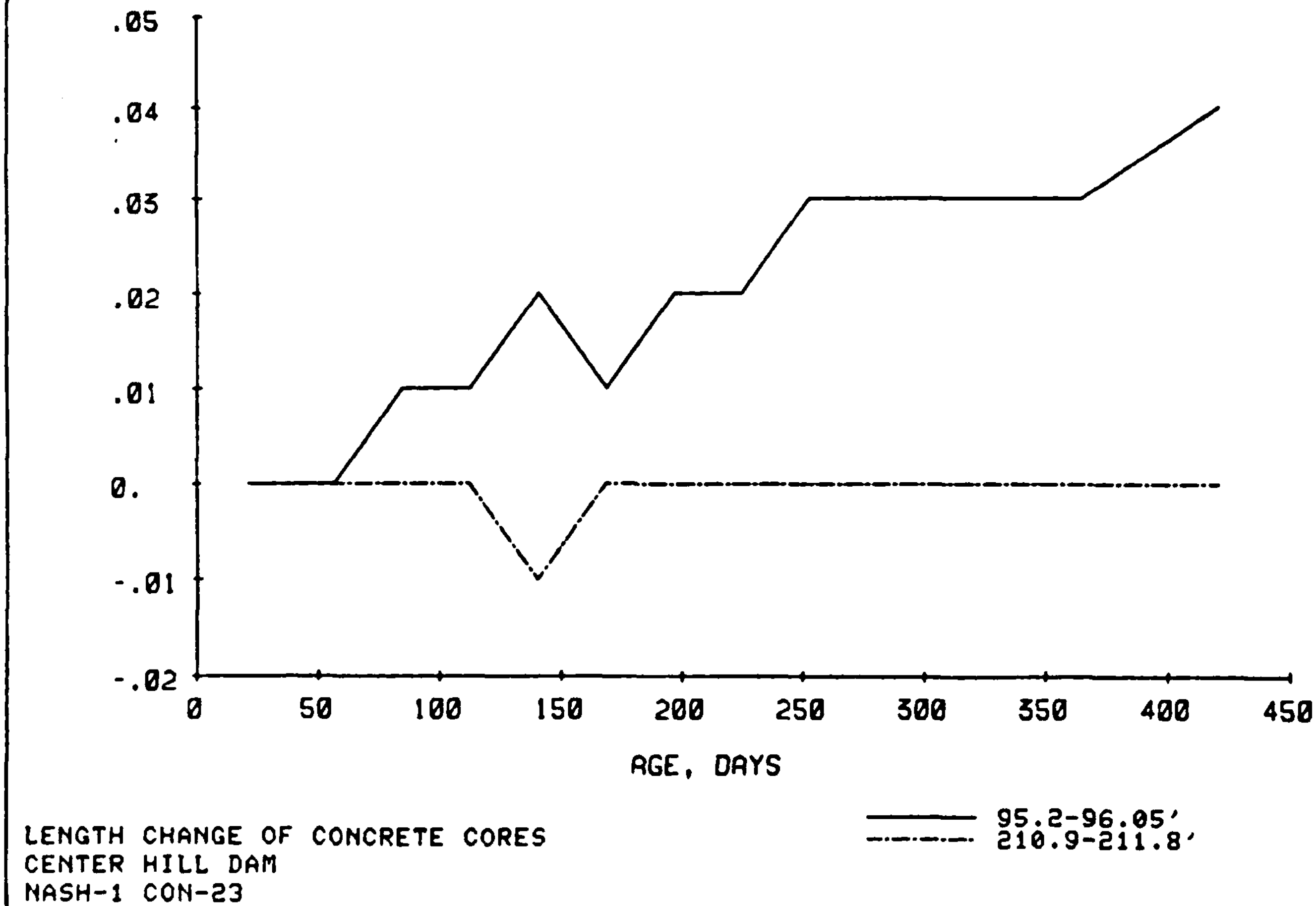

.05
.04
.03
.02
.01
0.
-.01
-.02
0
50
100
150
200
250
300
350
400
450
AGE, DAYS
95.2-96.05'
210.9-211.8'
LENGTH CHANGE OF CONCRETE CORES
CENTER HILL DAM
NASH-1 CON-23

Figure 24

END

FEb.

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