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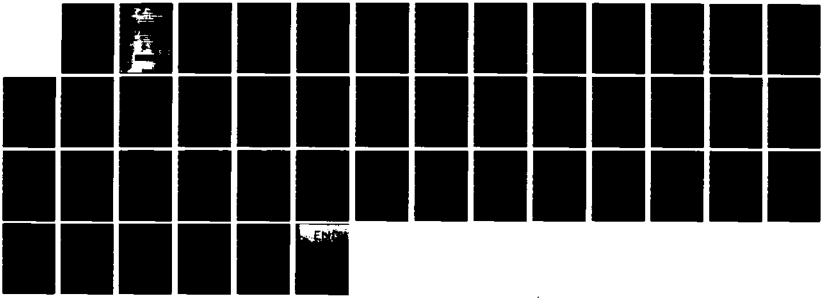

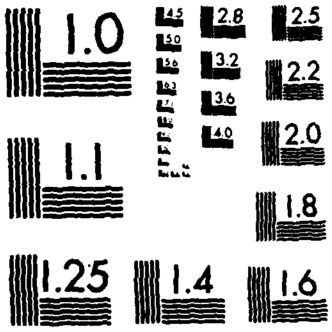

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MISSISSIPPI RIVER

STUDY OF ALTERNATIVES FOR REHABILITATION OF LOCK AND DAM NO. 1

MINNEAPOLIS, MINNESOTA

A134 266

SUPPORTING DATA
FOR
APPENDIX E
EVALUATION STUDY

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INLAND WATERWAYS
MISSISSIPPI RIVER
CONCRETE

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

It is recommended that both the landward lock, the riverward lock and the dam at Lock & Dam no. 1, Minneapolis, Minnesota be completely rehabilitated. Based on studies completed to the date of this report, more detailed studies are required to firmly establish cost estimates, environmental effects, and the construction scheduling necessary to insure the work can be completed in the proposed two year construction period without delaying navigation.

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DEPARTMENT OF THE ARMY
ST. PAUL DISTRICT, CORPS OF ENGINEERS
1210 U.S. Post Office & Custom House
St. Paul, Minnesota 55101

MISSISSIPPI RIVER
STUDY OF ALTERNATIVES FOR REHABILITATION OF LOCK AND DAM NO. 1
MINNEAPOLIS, MINNESOTA

SUPPORTING DATA FOR APPENDIX F CONCRETE EVALUATION STUDY

REPORTS

Number No.	
1	R. C. Mielenz, Petrographic Examination of Concrete, Lock and Dam No. 1, St. Paul, Minnesota, August 31, 1974,
2	R. C. Mielenz, Petrographic Examination of Samples of Concrete, Lock and Dam No. 1, Mississippi River, October 15, 1974;
3	R. C. Mielenz, Petrographic Examination of Concrete Core Specimens, Lock and Dam No. 1, Mississippi River, December 9, 1974.

PETROGRAPHIC EXAMINATION OF SAMPLES OF CONCRETE, LOCK AND DAM NO. 1, ST. PAUL, MINNESOTA

INTRODUCTION

In accordance with the letter of transmittal dated August 6, 1974, from Mr. Gary R. Mass, Concrete and Materials Engineer, Harza Engineering Company, Chicago, Illinois, I have examined by petrographic methods concrete core specimens that were received on August 14, 1974, by United Parcel Service.

The samples were identified as portions of NX core, 2 to 3 in. in length, taken at random intervals from three drill holes. The project was identified as Lock and Dam No. 1, Harza Engineering Company Project No. 800A, St. Paul, Minnesota, located on the Mississippi River. The samples were identified as follows:

Drill Hole No.	74-48	74-39	74-50
Location	River Wall	Center Wall	Land Wall
Date Placed	1900-08	1930	1931-32
Sample Depth, ft.	2.4	0.6	1.6
	9.2	6.8	9.5
	17.7	13.2	16.2
	23.8	21.2	27.3
	31.7	29.9	35.2
	37.1	37.2	42.7
	44.4	44.0	43.7*
	48.1*	52.0	52.4
		56.5	59.0

* Not listed in the letter of transmittal.

It was requested that the samples be examined to determine the overall condition and integrity of the concrete in each drill hole. Each of the specimens was examined visually and in detail under the stereoscopic microscope. For each drill hole, a selection of specimens was prepared by sawing and lapping so as to permit detailed examination of the internal structure of the concrete in an undisturbed condition when viewed at high magnification. Such sections facilitate the detection of microcracking within the cement paste and mortar matrix, in aggregate particles, or at the boundary of aggregate particles; evidences of cement-aggregate reactions; the occurrence of secondary chemical deposits with cracks, air voids, or at aggregate boundaries; variations of texture and composition within the cement paste; and identification of aggregate constituents without destruction of the concrete specimen. Selected portions were examined in immersion oils under the petrographic microscope.

CONCLUSIONS

River Wall, Drill Hole No. 74-48

1. The concrete includes crushed dolomite coarse aggregate and a natural sand fine aggregate. No finely divided mineral admixture is present in the matrix of essentially completely hydrated portland cement.

2. The concrete is relatively weak at a depth of 2.4 ft. but is moderately hard at greater depth. The fresh concrete was subject to significant bleeding (water gain), which resulted in separations beneath particles of coarse aggregate and variability of firmness and porosity of the cement paste matrix because of variation of water-cement ratio and accumulation of aggregate fines. The concrete represented by the samples is free from significant cracking, except for isolated microcracking specifically related to particles of aggregate involved in the alkali-silica reaction (see below). No evidence of progressive deterioration of the cement paste matrix, such as sulfate attack or leaching was found.

3. The dolomite coarse aggregate was subject to a moderate degree of the so-called alkali-silica reaction and possibly to the alkali-carbonate rock reaction as well. These reactions involve the attack of the alkalies sodium and potassium, primarily originating the cement, upon constituents of the aggregate. In the case of the alkali-silica reaction, the susceptible constituents in the dolomite were not identified specifically, but are probably very finely divided quartz and microcrystalline quartz that is present in silty and clayey fractions within the matrix of the dolomite. Some writers studying somewhat similar rock types have concluded that illitic clay is susceptible of deleterious alkali-silica reactions in concrete; illite is present also within the matrix of the dolomite.

In any event, the examination of the submitted samples reveals the occurrence of moderately extensive alkali-silica reaction, the effects being formation of periperal reaction rims on affected particles, minor microcracking within the rock particles, very rare microcracking of the adjacent cement paste matrix of the concrete, and production of moderate to copious amounts of alkalic silica gel, most of which has now been converted by reaction with calcium hydroxide into limited swelling calcium-alkali-silica gels.

4. The sand fine aggregate includes a variety of types of chalcedonic cherts which show evidences of the alkali-silica reaction in the form of softening, darkened rims, and stained of the adjacent cement paste matrix as a result of outward permeation of alkalic silica gel. However, except for occasional particles of a green chalcedonic chert, which occurs in pebbles as much as one inch across, no distress of the concrete was found to relate to alkali reactivity of the cherts. The green cherts are totally reacted, that is, converted to calcium-alkali-silica gels that are waxy in consistency and internally cracked and occupy the original volume of the aggregate particle. Except for particles of green chert whose minimum dimension exceeds about 7 mm (occurring in samples at 31.7, 37.1, and 48.1 ft.), no visible cracking of the adjacent matrix was found. However, in these three instances, cracks extend from the reacted chert particle into the surrounding matrix. In the occurrences at 31.7 and 48.1 ft., alkalic silica gel in copious amounts has spread outwardly and has created extensive cracking of the mortar matrix.

Although the larger particles of the highly reactive green chert were found at only the three depths, there is no reason to believe that they are not distributed sparsely throughout the entire mass of concrete. Their presence in the particular samples is the result of random chance.

5. In my opinion, the concrete represented by the sample of the drilled core is not in a condition of distress. The examination indicates that the alkali-silica reaction involving the dolomite coarse aggregate has terminated in the production of calcium-alkali-silica gels of limited swelling capacity, not unlike the calcium silicate hydrates that form the cement paste matrix of any portland cement concrete. Upon 48 hr. of soaking of the concrete, no gel exudations related to the dolomite aggregate were developed, whereas other concretes affected by progressive alkali-silica reaction produce obvious exudations and pop-outs during similar immersion as a result of rapid osmotic

swelling of alkalic silica gels already present in the aggregate or in cracks and voids.

As noted above (Conclusion 4), active alkalic silica reaction is present in the relatively rare, large particles of the green chalcedonic chert. Such particles constitute only a fraction of one percent of the sand fine aggregate, according to the sampling represented by the concrete submitted. In the particles of green chert which are in a size range less than about 7 mm in diameter the chalcedonic matrix is converted entirely to limited swelling calcium-alkali-silica gels. Only in the very rare larger particles has the residue of alkalic silica gel within the core of the particle been preserved where it is subject to development of high swelling pressure upon wetting. However, even here, considering that the potential swelling pressure is only on the order of 600 psi, potential distress is to be expected only where the confining pressure is less than this amount.

6. The potential for residual expansion of the concrete can be determined by laboratory testing of core specimens that are fitted with gauge points and are maintained in a moist atmosphere for an extended period, during which length change measurements are made.

Land Wall, Drill Hole No. 74-50

7. The concrete includes a natural gravel and sand as aggregate. No finely divided mineral admixture is present in the matrix of essentially completely hydrated portland cement.

8. The concrete is moderately hard and sound. The fresh concrete was not subject to significant bleeding. The concrete represented by the samples is free from significant cracking, except for isolated microcracking related to specific particles of aggregate involved in the alkali-silica reaction (see below).

9. The gravel is of complex lithologic composition, but is structurally sound and suitable as aggregate for mass or structural concrete. Among the constituents of the gravel only particles of a red silty sandstone show evidence of the alkali-silica reaction; the evidences of such reaction are peripheral darkened reaction rims, meager deposits of calcium-alkali-silica gel, and occasional cracking within the affected aggregate particle. No cracking of the mortar matrix was discovered in relation to such particles.

10. The sand fine aggregate is very similar to that described above (Conclusion 4). The large particles of highly reactive green chert are less abundant. The only particle of such chert found in these samples occurred at 59.0 ft. The particle is 8 mm in diameter and had caused cracking of the mortar matrix with accompanying release of white alkalic silica gel.

11. In my opinion, the concrete represented by the sample from Drill Hole No. 74-50 is in satisfactory condition. No distress was indicated by the examination. Only incipient alkali reactivity was found in the coarse aggregate, this being in relation to particles of red quartzose silty sandstones. The examination indicates that this reaction has terminated with the production of calcium-alkali-silica gels of limited swelling capacity. Upon 48 hr. immersion of the concrete in water, no gel exudations related to the reactive particles of coarse aggregate were found.

As noted above (Conclusion 4), active alkalic silica reaction is present in the rare large particles of the green chalcedonic chert within the sand fine aggregate. Such particles constitute only a fraction of one per cent of sand according to the sampling represented by the concrete submitted.

Center Wall, Drill Hole No. 74-39

12. The concrete includes a natural gravel and sand as aggregate. No finely divided mineral admixture is present in the matrix of essentually completely hydrated portland cement.

13. The concrete is moderately hard and sound. It is very similar in composition, quality, and occurrence of the alkali-silica reaction to the samples from Drill Hole No. 74-50, except that the degree of alkali reactivity is less in the present sample. The concrete represented by the samples is free from significant cracking, except for isolated microcracking related to specific particles of aggregate involved in the alkali-silica reaction (see below).

14. The discussion of aggregate reactivity given in Conclusions 9 and 10 (above) is applicable here, except that a low degree of reactivity was detected in a particle of red siltstone within the gravel in this set of samples (0.6 ft.). Incipient reaction was observed in various particles of chert in the fine aggregate and several particles

of completely reacted green chert were found in various of the samples, but no particles of green chert large enough to contain alkalic silica gel were detected. However, it is to be expected that such large particles of chert exist within the concrete, although in very rare distribution and without significant effect on the integrity of the concrete constructions.

15. In my opinion, the concrete represented by the sample from Drill Hole No. 74-39 is in satisfactory condition. No distress was indicated by the examination. Only incipient alkali reactivity was found in the coarse and fine aggregates. The examination indicates that this reaction has terminated with the production of calcium-alkali-silica gels of limited swelling capacity. Upon 48 hr. immersion of the concrete in water, no gel exudations related to the reactive particles of aggregate were found. It is not precluded that additional sampling would show the presence of rare particles of green chert of sufficient size to retain alkalic silica gel possessing significant swelling potential; however, such rare distribution of reactive particles would not affect the integrity of the constructions.

DESCRIPTION OF THE SAMPLES

Drill Hole No. 74-48

General

The core was represented by 8 sections of NX specimens, approximately 2-1/16 in. in diameter. Each of the specimens was bounded at the upper and lower ends by fresh fractures along which they had been broken from the remainder of the core. Each of the samples was designated by the depth. The orientation of the specimen in the hole was evident in each case.

2.4 feet

The section was 1-1/2 to 2-1/2 in. long. The fracture surfaces at both ends are partially coated by copious, white deposits of dried and brittle siliceous gel in sockets of coarse aggregate. Several particles of coarse aggregate had been broken across when the specimen was taken from the core. Prominent separations beneath particles of the coarse aggregate demonstrate copious bleeding of the fresh concrete.

The concrete is relatively weak although well compacted. The cement paste matrix is firm and off-white in color except beneath particles of coarse aggregate, where it is soft, granular in appearance, and pale buff in color as a result of accumulation of an abundance of aggregate fines. Air voids and separations adjacent to aggregate particles are lined or filled by white siliceous gel with or without accompanying deposits of high-sulfate calcium sulfoaluminate (ettringite). Except for very minor amounts of clear alkalic silica gel, the gel is white and highly carbonated, with index of refraction above 1.55, a fact that shows that it is mainly a calcium-silica gel, probably in combination with subordinate alkali content so that it may be designated as a calcium-sodium (potassium)-silica gel or calcium-alkali-silica gel. In the core as received, the gel is firm to brittle; the gel is softened by immersion in water but no exudations were produced by 48 hr. of immersion.

Under the petrographic microscope, unhydrated portland cement is seen to be very rare; the cement is almost completely hydrated. No finely divided mineral admixture was employed. The cement paste is highly carbonated as a result of penetration by atmospheric carbon dioxide. The examination revealed no evidence of progressive deterioration of the cement paste matrix, as by sulfate attack or leaching. On fresh fracture produced in the laboratory by breaking the concrete by means of a small hammer, the cement paste is subvitreous to lackluster in appearance. Sound sand grains are not broken across, a fact that indicates weakness of the cement paste and inferior bond of the matrix with the aggregate.

The coarse aggregate is a crushed and graded, gray, moderately hard, compact dolomite that contains a substantial proportion of fine-grained quartzose sand and silt as well as illitic clay. Portions of the rock grade to a calcareous graywacke. Pyrite is common as scattered crystals and segregations. Calcite is a subordinate constituent. The particles of coarse aggregate show abundant evidence of the alkali-silica reaction and possibly the alkali-carbonate rock reaction as well. The darker particles (more charged with clayey siliceous matter) commonly display partial peripheral reaction rims within the particle and usually 0.1 to 1.0 mm thick. Deposits of white siliceous gel, as described above, are common at the boundary with the cement paste and also in adjacent air voids in the mortar matrix. The perimeter of the particles of coarse aggregate occasionally includes subradiate or circumferential microcracks that usually terminate at the boundary of the particle and only rarely can be traced into the adjacent cement paste matrix.

The fine aggregate is a natural sand of complex lithologic composition, the main constituents being quartz, quartzites, granitic rocks, gneisses, feldspars, graywackes, light-colored dolomites, limestones, red siltstones and fine-grained sandstones, diabase, and rare particles of tan, white, or gray chalcedonic cherts. The chert are softened as a result of the alkali-silica reaction and include a peripheral rim, but no free gel or related cracking was detected.

9.2 feet

The section was 2 to 3-1/8 in. long. The fracture surfaces at both ends include small to moderate amounts of white siliceous gel in air voids and in aggregate sockets. The upper end includes particles of coarse aggregate that were fractured across when the specimen was taken; no such fracturing occurred at the lower surface. Prominent bleeding of the fresh concrete is indicated.

The concrete is similar in composition and quality to that at 2.4 feet except that it is moderately hard. No microcracking was observed in the cement paste matrix or in particles of aggregate. The cement paste is firm, light gray, and vitreous to subvitreous on fresh fracture produced in the laboratory. Sound sand grains commonly are broken across when the concrete is broken in the laboratory.

The coarse aggregate displays only incipient alkali-silica reaction. Reaction rims are absent or up to 0.2 mm thick. Siliceous gel development is restricted to meager amounts of carbonated, calcium-alkali gel in voids, accompanied by small amounts of ettringite and granular calcite. White chert in the sand is softened, displays a reaction rim, and has soaked the adjacent cement paste with siliceous gel resulting from the alkali-silica reaction. No gel exudations developed during 48 hr. immersion of the concrete and the gel remained firm.

17.7 feet

The sample was 1 to 2-3/8 in. long. Moderate bleeding of the fresh concrete is indicated. Minor amounts of siliceous gel are present on the fracture surfaces at either end. Several particles of aggregate were intersected by the fracture surfaces at the end, but in each case the surface passed around a large piece of coarse aggregate.

The concrete is moderately hard and is very similar to that at 9.2 ft. in composition and quality, except that the cement paste matrix is more variable in water-cement ratio. On fresh fracture produced in the laboratory, the cement paste ranges from vitreous to lack-luster in appearance and the extent of aggregate fracture is quite variable.

Only meager amounts of siliceous gel are present. The gel is of the calcium-alkali-silica type and is highly carbonated.

23.8 feet

The section was 2-1/4 to 3-1/4 in. long. Moderate bleeding of the fresh concrete is indicated. Only trace amounts of siliceous gel are present on the fracture surfaces. Aggregate fracture is common in the bounding fracture surfaces.

The concrete is very similar to that at 17.7 ft. A 3 mm particle of olive-green chalcedonic chert in the sand is totally reacted throughout its thickness and several narrow, radial cracks extend less than 0.5 mm into the adjacent cement paste; however, no free gel was detected. Several particles of white and gray chert include reaction rims and are softened, but no free gel or cracking of the adjacent matrix was found. Elsewhere, meager deposits of calcium-alkali silica gel occur at the perimeter of particles of dolomite coarse aggregate.

No gel exudations developed during 48 hr. of immersion in water.

31.7 feet

The section was 1 to 1-3/4 in. long. Minor bleeding of the fresh concrete is indicated. A moderate frequency of aggregate fracture is found at the lower bounding surface of the section but only minor amount at the top. Deposits of white siliceous gel are present in minor amounts.

The concrete is similar to that at 17.7 ft. A flat particle of green chalcedonic chert occurring in the fine aggregate (up to 5 mm thick and 20 mm in diameter) is totally reacted and cracked internally; cracks with fillings of alkalic silica gel penetrate the adjacent mortar matrix parallel to the long dimension of the particle. Elsewhere, meager amounts of white, carbonated calcium-alkali-silica gel occur in air voids and along aggregate sockets. Peripheral cracking with associated white calcium-alkali-silica gel occurs sparsely within particles of gray dolomite coarse aggregate.

37.1 feet

The section was 1-1/2 to 3-3/8 in. long. Honeycomb cavities are up to 3/4 in. across. Minor bleeding of the fresh concrete is indicated. Minor aggregate fracture occurs in the boundary fracture; most of the aggregate particles in the surfaces were not broken across during the taking of the sample. Very minor amounts of siliceous gel are present on the fracture surfaces at the ends of the section.

The concrete is very similar to that at 17.7 ft. Particles of white, green, and tan chalcedonic chert are softened throughout. White, brittle deposits of carbonated calcium-alkali-silica gel are well developed in sockets occupied by dolomite coarse aggregate and in air voids, where it occurs in association with ettringite. A particle of green chalcedonic chert 2.0 mm thick and 7.5 mm wide is totally reacted and is associated with cracking of the adjacent mortar matrix. No gel exudations were formed on the specimen during 48 hr. of immersion.

A large, tan piece of dolomite coarse aggregate includes an open crack that extends across its entire diameter except that it terminates at either end 1.3 mm from the perimeter at the inner edge of a dark reaction rim. Carbonated calcium-alkali-silica gel occurs in meager amounts at the perimeter of the particle and in adjacent air voids.

44.4 feet

The specimen was 2 to 2-3/8 in. long. Minor bleeding of the fresh concrete is indicated. Prominent aggregate fracture is present in both the upper and lower bounding surfaces. Very minor amounts of siliceous gel are present in the terminal fracture surfaces.

The concrete is very similar to that at 17.7 ft. Meager amounts of white, carbonated calcium-alkali silica gel are present at the perimeter of particles of dolomite coarse aggregate. Occasional reaction rims are 0.1 to 0.2 mm wide. Ettringite is common in air voids.

A totally reacted particle of green chalcedonic chert is 2.5 mm in diameter. No gel exudations developed during 48 hr. of immersion in water.

48.1 feet

The section is 1-3/4 to 2-1/2 in. long. No bleeding of the fresh concrete is indicated. The lower fracture surface displays frequent aggregate fracture, but none occurred in the upper surface. Minor white deposits of siliceous gel are present on the fracture surfaces.

A pebble of olive green chalcedonic chert, 12 by 25 mm in size, is totally reacted and intensely cracked internally. White, alkalic silica gel had spread onto the perimeter of the core and the adjacent mortar had been caused to spall as a result of hydraulic pressure.

A large air void is lined by calcium-alkali-silica gel and coarsely crystalline calcite. This type of gel occurs also at the perimeter of dolomite coarse aggregate and in smaller voids.

Drill Hole No. 74-50

General

The core was represented by 9 sections approximately 2-1/16 in. in diameter. Each of the sections was bounded at the upper and lower ends by fresh fractures produced when the section was secured from the remainder of the core. Each of the samples was designated by the depth. The orientation of the specimen in the hole was evident in each case.

1.6 feet

The section was 1 to 2-1/4 in. long. A large piece of coarse aggregate is broken across in the lower surface whereas only sparse aggregate fracture occurs above. Moderate deposits of siliceous gel are present in the surfaces. No significant bleeding of the fresh concrete is indicated. Air voids and other cavities are as large as 7/16 in.

The concrete is moderately hard. On fresh fractures produced in the laboratory by breaking the concrete in the laboratory by means of a small hammer, the cement paste matrix is seen to be firm, subvitreous in luster, and light gray in color. Occasional particles of sound fine aggregate, such as quartz, are broken across by the fresh fracture, a fact that indicates firmness of the matrix and adequate bond to the aggregate. Under the petrographic microscope, the cement paste matrix is normal in appearance and uncarbonated or only moderately carbonated as a result of penetration by atmospheric carbon dioxide. Calcium hydroxide is present in small segregations as is typical of concrete of satisfactory water-cement ratio. The cement is completely hydrated. No finely divided mineral admixture is present. Ettringite is present in small amounts in air voids throughout the section.

The aggregate is a natural gravel and sand, the apparent maximum size being at least 1-1/2 in. The gravel is composed mainly of red silty sandstones, graywackes, granitic rocks, gneisses, diabase, basalts, and sandy limestones. A large pebble of red silty sandstone occurs at the lower end of the section and is transected by the terminal fracture surface. A portion of the fracture surface within the pebble was pre-existing (before drilling of the core) and is partially coated by meager, white deposits of siliceous gel, particularly in a band extending 1 to 3 mm inward from the outer surface of the particle. Similar calcium-alkali-silica gel in association with ettringite forms a thin lining on adjacent air voids. Other particles of the red silty sandstone in the specimen also display a peripheral reaction rim and meager deposits of white, calcium-alkali-silica gel. No cracking of the mortar matrix in relation to the affected particles was detected.

The sand fine aggregate is complex in lithologic composition, being composed of red ferruginous sandstones and silty sandstones, graywackes, granitic rocks, gneisses, feldspars, light-colored dolomites, limestones, diabase, basalts, and occasional chalcedonic cherts. The chert particles frequently exhibit softening in the interior, peripheral rim formation, and staining or darkending of the adjacent cement paste matrix by penetration of alkalic silica gel. No cracking or other distress of the matrix was observed in relation to such reacted particles.

9.5 feet

The section was 1 to 2 in. in length. The upper end displays frequent aggregate fracturing whereas no coarse aggregate is intersected by the lower surface. No significant bleeding of the fresh concrete is indicated. Very meager amounts of white siliceous gel are present on the end surfaces.

The concrete is very similar to that at 1.6 feet in quality and composition and in the evidences of some alkali reactivity of certain constituents of the coarse and fine aggregate. Likewise, ettringite is present throughout the specimen in small amounts, mainly in air voids. The coarse aggregate is mainly a cream-colored, moderately hard dolomite that shows no appreciable reactivity. Other constituents of the aggregate are as noted above (1.6 ft.).

A grain of green chalcedonic chert in the sand is totally reacted but with no micorcracking of the adjacent matrix.

16.2 feet

The section is 1-7/8 to 2-9/16 in. long. Minor aggregate fracture occurs at both ends of the piece. No significant bleeding of the fresh concrete is indicated. Only trace amounts of white siliceous gel are present in the fracture surfaces.

The concrete is very similar to that at 9.5 ft. Small particles of green chalcedonic chert in the sand are reacted throughout. Light-colored cherts in the sand are softened, display peripheral rims, and the adjacent cement paste is stained by alkalic silica gel.

No gel exudations occurred during 48 hr. immersion of the concrete.

27.3 feet

The section was 1-3/16 to 2-14 in long. No significant bleeding of the fresh concrete is indicated. Frequent aggregate fracture occurred in the ends of the section. White deposits of siliceous gel are conspicuous in pebble sockets.

The concrete is similar to that at 9.5 ft. White, calcium-alkali silica gel and ettringite form a lining on pebble sockets at both ends and in the perimeter of the core, but the identity of the offending rock type could not be determined because the aggregate particle itself had broken out cleanly and was not supplied with the sample.

A 4-mm diameter particle of green chalcedonic chert in the sand is totally reacted and white alkalic silica gel has spread outwardly up to a centimeter over a fractured surface; the interior of the particle includes a small body of white alkalic silica gel. Occasional particles of red silty sandstone in the sand show meager silica gel formation and faint peripheral reaction rims.

35.2 feet

The section was 1-5/8 to 2-1/8 in. long. No significant bleeding is indicated. Aggregate fracture is common at both ends of the section. No siliceous gel is visible on the surfaces of the piece.

The concrete is very similar to that at 9.5 ft. Under the stereoscopic microscope, very meager amounts of ettringite and hard, white, calcium-alkali-silica gel are to be found in occasional aggregate sockets and in air voids. Sparse particles of chalcedonic cherts in the sand are softened, show reaction rim formation, and stain the adjacent matrix.

No gel exudation developed during 48 hr. of immersion in water.

42.7 feet

The section was 1-7/8 to 2-1/2 in. long. No significant bleeding is indicated to have occurred in the fresh concrete. Only trace amounts of siliceous gel are visible on the fracture surfaces. Aggregate fracture is common on both end surfaces.

The concrete is very similar to that at 9.5 ft. A moderate amount of white, calcium-alkali-silica gel occurs in aggregate sockets and air voids. Ettringite is somewhat more common in similar occurrences. Occasional particles of variously colored chalcedonic cherts in the sand are softened, rimmed, and surrounded by a stained zone in the adjacent cement paste as a result of release of alkalic silica gel.

No exudations of gel developed during water immersion for a period of 48 hours.

43.7 feet

The section is 2-3/16 to 2-3/4 in. long. No significant bleeding is indicated. Only very minor amounts of siliceous gel are visible on the exposed surfaces. Moderate aggregate fracture occurred at the upper surface, but no coarse aggregate was intersected by the lower surface.

The concrete is similar to that at 9.5 feet. Very meager amounts of ettringite and hard, white, calcium-alkali-silica gel occur in air voids and aggregate sockets. The main reactive type of coarse aggregate is ferruginous, red to tan, silty sandstone. A particle of green chalcedonic chert in the sand is completely reacted but no distress is evident in the enclosing matrix.

No gel exudations developed during 48 hours of water immersion.

52.4 feet

The section was 2-1/2 to 2-9/16 in. long. No significant bleeding is indicated. Moderate aggregate fracture occurred at both ends of the section. Only trace amounts of siliceous gel are present on the surfaces.

The concrete is very similar to that at 9.5 feet. Meager amounts of calcium-alkali-silica gel occur in sparse pebble sockets and in air voids, commonly with small amounts of ettringite. A totally reacted particle of green chalcedonic chert, 2 mm across, was not associated with evident distress of the enclosing matrix.

No gel exudations occurred during 48 hours of immersion.

59.0 feet

The section is 1-7/16 to 2 in. long. No significant bleeding is indicated. Only sparse aggregate fracture occurs at the ends of the section. Only trace amounts of siliceous gel are present on exposed surfaces.

The concrete is very similar to that at 9.5 feet. A particle of green chalcedonic chert up to 8 mm across is totally reacted; minor amounts of white alkalic silica gel have penetrated into the adjacent matrix and minor microcracking of the matrix has developed. Otherwise, only meager amounts of calcium-alkali-silica gel and ettringite are present in voids and at pebble boundaries.

Drill Hole No. 74-39

General

The core was represented by 10 pieces that were approximately 2-1/8 inches in diameter. Each of the sections was bounded above and below by a fresh fracture along which the piece had been removed from the core. Each of the samples was designated by the depth. The orientation of the specimens was evident in each case.

0.6 feet

The section was 2 to 3 in. long. Minor bleeding was indicated. Aggregate fracture was common at both ends of the section. Only trace amounts of siliceous gel are visible on the exposed surfaces.

The concrete is moderately hard. On fresh fractures produced in the laboratory by breaking the concrete by means of a small hammer, the cement paste is vitreous to subvitreous in luster. Sound particles of sand commonly are broken across, indicating firmness of the matrix and good bond of the matrix to the aggregate. Under the petrographic microscope, the cement paste matrix is normal in appearance and is uncarbonated or only moderately carbonated. Calcium hydroxide is in normal distribution and is in small segregations that typify a satisfactory range of water-cement ratio. The cement is completely hydrated. No finely divided mineral admixture is present.

The air voids are empty or are lined by thin deposits of ettringite or scattered crystals of ettringite.

The coarse aggregate is a natural gravel similar to that occurring in the concrete of Core No. 74-50. The main constituents are graywackes, granitic rocks, gneisses, light-colored dolomites, quartzites, quartzose sandstones, ferruginous quartzose and silty sandstones, red siltstones, basalts, and diabases. Some particles of the red ferruginous, silty sandstones show peripheral rims up to 1.0 mm thick, but no conclusive evidences of the alkali-silica reaction were found. A particle of hard, red siltstone shows meager white calcium-alkali-silica gel in internal fractures.

The fine aggregate is a natural sand similar to that in the concrete of Core No. 74-50, the main constituents being quartz, quartzites, granitic rocks, gneisses, feldspars, red quartzose and silty sandstones, basalts, diabases, graywackes, dolomites, and a variety of chalcedonic cherts. The cherts show rim formation and softening but no distress of the adjacent matrix.

No gel exudations developed during 48 hours of water immersion.

6.8 feet

The section is 1-1/2 to 2-1/4 in. long. No significant bleeding is indicated. Frequent aggregate fracture occurred at both ends. No siliceous gel is visible of exterior surfaces.

The concrete is like that at 0.6 feet. A grain of green chalcedonic chert (3.5 mm diameter) is totally reacted but no distress is evident in the adjacent matrix. Several other types of chalcedonic chert in the sand are softened, show rim formation, and staining of the adjacent matrix. Otherwise, no evidence of the alkali-silica reaction was detected.

Ettringite is slightly more abundant than in the core at 0.6 feet in air voids.

13.2 feet

The section was 1-1/2 to 3-1/4 in. long. No significant bleeding was indicated. Common aggregate fracture occurred at the upper surface but is absent at the lower surface. No deposits of white gel were observed.

The concrete is similar to that at 0.6 feet. A totally reacted particle of green chalcedonic chert in the sand (up to 4.5 mm across) was not associated with any apparent distress of the matrix.

Small amounts of ettringite occur in air voids.

No exudations of gel developed during 48 hours of immersion.

21.2 feet

The section was 2-1/8 to 3 in. long. No significant bleeding is indicated. Only minor aggregate fracture occurred at either end. Only trace amounts of white siliceous gel were observed on exposed surfaces.

The concrete is similar to that at 0.6 feet. Totally reacted particles of green chalcedonic chert in the sand (up to 3.5 mm in diameter) are not associated with evident distress of the matrix. Air voids are lined by ettringite or filled by white to clear siliceous gel in combination with ettringite.

No gel exudations were developed during 48 hours of immersion.

29.9 feet

The section was 2-1/8 to 2-1/2 in. long. No significant bleeding was indicated. No aggregate fracture occurred at the upper surface, but frequent fracturing occurred below. Trace amounts of white siliceous gel are present.

The concrete is very similar to that at 0.6 feet. Meager amounts of ettringite and white calcium-alkali-silica gel occur in air voids. Occasional particles of chert in the sand are slightly softened and show rim formation.

No gel exudations developed during 48 hours of immersion.

37.2 feet

The section is 1-3/8 to 2-3/8 in. long. No significant bleeding is indicated. Only minor aggregate fracture occurred at either end of the section. No white gel is visible on exposed surfaces.

The concrete is similar to that at 0.6 feet. Scattered air voids include ettringite as partial linings. Several particles of green chalcedonic chert up to 3 mm across are totally reacted but have produced no evident distress in the adjacent matrix.

No gel exudations developed during 48 hours of immersion.

44.0 feet

The section is 1-1/2 to 2-7/8 in. long. No significant bleeding is indicated. Only minor aggregate fracture occurred at either surface. No deposits of white siliceous gel are visible on exposed surfaces.

The concrete is similar to that at 0.6 feet. Neither ettringite or gel deposits were found, except for sparse particles of softened white chert in the coarse sand. No distress of the matrix was found.

No gel exudations developed during 48 hours of immersion.

50.2 feet

The section was 2-1/2 to 3-1/4 in. long. No significant bleeding was indicated. Only minor aggregate fracture occurred at either end. No deposits of white gel were detected on exposed surfaces.

The concrete is similar to that at 44.0 feet. Totally reacted particles of green chalcedonic chert are as large as 6.0 mm across but no related distress of the matrix was found. Meager amounts of ettringite are present in air voids.

No exudations of gel developed during 48 hours of immersion.

56.5 feet

The section was 2-3/8 to 3-1/4 in. long. No significant bleeding was indicated. No aggregate fracture occurred at either end. Several cavities more than 2 cm across are present as a result of inadequate consolidation of the fresh concrete. No siliceous gel is present on exposed surfaces.

The concrete is similar to that at 44.0 feet. The air voids are empty of secondary deposits, such as gel or ettringite. Sparse particles of tan or gray chert in the coarse sand fractions are softened and display rims, but no distress of the matrix is evident.

No gel exudations developed during 48 hours of immersion.

Richard C. Mielenz, P. E.
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August 31, 1974

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RICHARD C. MIELENZ — GEOLOGIST AND PETROGRAPHER

PETROGRAPHIC EXAMINATION OF SAMPLES OF CONCRETE, LOCK AND DAM NO. 1 MISSISSIPPI RIVER

INTRODUCTION

In accordance with the letter of transmittal dated September 10, 1974, from Mr. E. T. Moore, Project Manager, Harza Engineering Company, Chicago, Illinois, I have examined by petrographic methods four samples of portland-cement concrete that were received by truck freight on September 21, 1974.

The shipment consisted of four sections of nominally 6-in. diameter drilled cores designated as Nos. 1 through 4, respectively. The samples were secured in connection with proposals for rehabilitation of concrete structures of Lock and Dam No. 1 - Mississippi River. Three of the samples were said to have been taken from the Land Wall of the locks, which shows most severe damage in the form of extensive spalling at various locations. It was requested that the samples be examined to provide an assessment of the surface condition and soundness of the concrete.

One of the core was taken from the land side of the Center Wall and was submitted for examination and comparison. The concrete in this location appears to be sound.

Unfortunately, the identification of the source of the respective cores was not indicated. However, from the appearance of the samples, it is presumed that Core No. 4 was taken from the Center Wall.

The samples were examined visually and in detail under the stereoscopic microscope. For each of the cores a section parallel to the length was prepared by sawing and lapping so as to allow examination of the concrete in an undisturbed condition. Selected portions of the concrete were examined in immersion oils under the petrographic microscope.

CONCLUSIONS

1. The four samples of concrete are alike in the quality and composition of the coarse and fine aggregates and the original quality of the concrete as placed. The aggregates are natural gravel and sand, the apparent nominal maximum size

being 1-1/2 in. In all instances, the concrete was well compacted and cured and shows no evidence of significant bleeding or segregation before setting. As would be expected of concrete of the age of this construction, the concrete is not air entrained.

2. Cores No. 1, 2, and 3 show varying degrees of distress as the result of the alkali-silica reaction and the service exposure. These cores show the concrete to be so severely damaged by cracking and, in the outer portions of Cores Nos. 1 and 3, by chemical deterioration of the matrix to require consideration of removal to the following depths in preparation for restoration:

Core No. 1	1-1/4 to 4-1/2 in. from the existing surface
Core No. 2	At least 10-1/2 in. (representing the depth penetrated)
Core No. 3	Approximately 7 in. from the formed surface.

3. Three destructive agents have been effective in causing the observed distress of the concrete, namely, (1) alkali-silica reaction, primarily involving certain constituents of the coarse aggregate, (2) sulfate attack upon the cement paste matrix, and (3) freezing and thawing while the concrete was saturated or nearly saturated by water.

a. The alkali-silica reaction is evident in all of the cores, including Core No. 4, which was submitted for comparison and shows no significant distress. This reaction is most well developed in Core No. 1, in which particles of graywackes, red siltstones, and chalcedonic cherts are affected and have caused minor cracking of the matrix. This reaction is only incipiently developed in the remaining three cores and, in these three latter cores only the cherts and siltstones are involved. In my opinion, the alkali-silica reaction has essentially terminated through the development of calcium-alkali-silica gels of limited swelling capacity.

b. Cores No. 1 and 3 display severe deterioration of the cement paste matrix adjacent to the exterior surface of the wall, with formation of copious secondary chemical deposits, cracking of the near-surface concrete, and spalling and general disintegration. The deposits include abundant amounts of the high-sulfate calcium sulfoaluminate (ettringite) and gypsum (calcium sulfate dihydrate) as a result of introduction of sulfate from an external source and its attack upon constituents, mainly the aluminates, that are a normal portion of portland cement hydration products. The attack has produced severe damage only to the depths noted above, but the presence of the secondary sulfates was detected throughout the length of the core sections submitted.

Core No. 2 showed minor effects of the sulfate attack but much less than that evident in Cores 1 and 3. No gypsum was found in Core No. 2, gypsum being a product of more extreme sulfate attack.

c. Although the evidences of its effects are indirect, freezing and thawing undoubtedly produced disintegration that is superimposed upon the distress resulting from sulfate attack and the alkali-silica reaction. Cracking resulting from these processes permits entry of water into the interior of the concrete, thus increasing the degree of saturation of the cement paste matrix and of porous, unsound particles of coarse aggregate. The cement paste matrix is susceptible of damage in freezing and thawing while in a wetted condition because of the lack of air entrainment and the fact that the water-cement ratio is in an intermediate range. As is noted in the text, a particle of white, highly porous chert lying 6 cm from the exterior surface had been disrupted internally and had produced subradiate cracks that extend into the surrounding mortar matrix; this phenomenon is common in concrete containing highly porous particles of this type when the particles are above a critical size, such as 3/8 to 1/2 in. for porous cherts. In such cases, failure is within the particle, rather than in the cement paste matrix.

In my opinion, freezing and thawing is the primary cause of the internal cracking of the concrete represented by Core No. 2. The repeated cracking oriented more or less parallel to the exposed face of the constructions is characteristic of the action of freezing and thawing of non-air-entrained concrete in a saturated or near-saturated condition. In this instance, the alkali-silica reaction and sulfate attack are subordinate but probably contributory agents.

4. The examination indicates that the restoration should be carried out with air-entrained concrete containing Type II cement, preferably in combination with a suitable fly ash admixture in an amount about 15 per cent by weight of the cement content to assure proper sulfate resistance. Use of aggregates not susceptible to the alkali-silica or alkali-carbonate rock

reaction is strongly recommended because of the possible availability of alkalies (sodium and potassium) from an external source in these constructions.

DESCRIPTION OF THE SAMPLES

Core No. 1

The sample was a section of 5-5/8 in. diameter drilled core of portland-cement concrete. The section of core was in three pieces as received; the fragments could be fitted together to form a section 9 to 9-3/4 in. long. The outer end was a completely scaled and disintegrated surface in which particles of coarse and fine aggregate were exposed, some of which had been broken across. The depth to which the disintegration had proceeded during service is not apparent. Embedded in the exterior surface is a particle of green chert, about 6 by 10 mm in area, that had been converted entirely into calcium-alkali-silica gels as a result of the alkali-silica reaction, and some of the gel had extruded over the adjacent surface of the mortar matrix. The exposed surface of a pebble of red siltstone also was coated by white siliceous gel resulting from the alkali-silica reaction.

The outer 1 to 3 in. of the core is weak and includes closely spaced but discontinuous cracks that are mainly approximately perpendicular to the longitudinal axis of the core. These fractures usually pass around particles of aggregate, but occasional particles are transected. The outer end of the core had broken away from the inner portion along an irregular, pre-existing fracture that lay 1-1/4 to 4-1/2 in. from the outer end of the core (exterior of the wall). The crack surface includes white deposits, both on portions of the mortar matrix and on surfaces of particles of aggregate that had been broken across. This fracture had transected a large pebble of black, hard, dense graywacke that showed abundant evidence of attack by the alkali-silica reaction, with development of a darkened reaction rim up to about 1.0 mm thick and copious deposits of white calcium-alkali-silica gel. Several smaller particles of graywacke and red siltstones are similarly affected. Several particles of chalcedonic chert up to 13 mm across are totally reacted and converted to wax-like calcium-alkali-silica gel. Exposed pebble sockets and the sparse air voids are lined by white deposits that are mainly calcium-alkali-silica gel and finely divided calcite (calcium carbonate); trace amounts of high-sulfate calcium sulfoaluminate (ettringite) and alkalic silica gel are present also.

The inner end of the core is a fresh fracture that intersects numerous particles of coarse aggregate. The intervening portion of the core, that is, the interval from a depth of 1-1/4 to 4-1/2 in. from the exterior surface to a depth of about 9 in., is free from fracturing except for a fracture extending about 1/2 in. into the outer end of the inner section. In other words, the deepest fracturing found in the sample lay at a depth of 5 in. However, evidences of the alkali-silica reaction are present throughout the length of the section.

The coarse aggregate is a natural gravel, the apparent nominal maximum size being 1-1/2 in. The main constituents are hard, dark green to black diabases; hard, dark gray to black graywackes and subgraywacke sandstones; fine to medium-grained granitic rocks and gneisses; moderately hard, dark gray to reddish basalts; moderately hard to weak, very fine-grained, compact, red siltstones and sandy siltstones; dense to porous, hard, quartzose sandstones; fine-grained, white to gray or buff, hard to moderately hard limestones and dolomites; rare particles of white, highly porous, chalcedonic chert; and rare particles of dark olive green chalcedonic chert. The siltstones, graywackes, and white cherts show reaction rims and occasional microcracking in association with the formation of siliceous gels that occur within fractures in the particles, soak into the adjacent cement paste matrix at the perimeter of the particles, and rarely penetrate into the adjacent matrix along microcracks for distances up to about 1.0 mm.

The fine aggregate is a natural sand. The coarse fractions are similar in lithologic composition to the accompanying gravel aggregate. The finer fractions are highly quartzose and feldspathic but include particles of white to buff, tan, or green chalcedonic cherts that typically display evidences of the alkali-silica reaction in the form of darkened and softened rims. The dark olive green cherts usually are totally reacted and converted to calcium-alkali-silica gels. No distress, such as cracking, was found in association with the occurrences of the alkali-silica reaction involving the fine aggregate.

The concrete in the near-surface portion of the core is weak and intensely fractured to a depth of up to 5 in. The fracture surfaces are coated by felted masses of ettringite together with finely divided calcite, calcium-alkali-silica gel, and gypsum. Platy calcium hydroxide is common in voids and separations at the perimeter of aggregate particles. Ettringite and gypsum also form compact bundles of irregular crystals within the cement paste matrix in the near-surface portion of the core. Gypsum is predominant at and immediately adjacent to the exposed surface.

The concrete at depth (greater than about 5 in.) is moderately hard, compact, and free from evidences of significant bleeding or segregation before setting. On fresh fractures produced in the laboratory by breaking portions of the concrete by means of a small hammer, the cement paste matrix is subvitreous in luster; sparsely distributed particles of sound fine aggregate, such as quartz grains, are broken across, a fact that indicates good quality of bond of the matrix to the aggregate. As noted above, evidences of incipient development of the alkali-silica reaction are present throughout the core. Under the petrographic microscope, the cement is seen to be almost completely hydrated. The cement paste is not carbonated. Calcium hydroxide is present in normal distribution in small or moderate-sized segregations. Ettringite is common in air voids and also is visible as occasional, strained bundles within the cement paste itself.

Core No. 2

The sample was a section of 5-5/8 in. diameter drilled core of portland-cement concrete. The section was in one piece. The outer surface is approximately plane and intact except for minor, granular disintegration that has produced a slightly friable texture with exposed particles of fine aggregate. The section is 8-7/8 to 10-1/2 in. long. The inner end is an irregular, pre-existing fracture that intersected several particles of coarse aggregate. Meager white deposits occur sparsely over this surface.

The concrete is generally similar to that of Core No. 1 in composition, but the entire length of the section of Core No. 2 includes readily apparent cracks and fractures that are predominantly perpendicular to the length of the core, but are found upon closer examination to ramify within the matrix and to intersect many particles of coarse aggregate. Such cracks and fractures were readily visible at the perimeter of the core at depths of 2-1/2, 3, 4-5/8 to 4-3/4, 6-3/4, and 7-1/2 to 8-1/2 in. and at the inner end of the section at a depth of 8-7/8 to 10-1/2 in. A large particle of white, hard but highly porous and absorptive chert lying 6 cm from the exterior surface had burst, with creation of subradiate cracks that pass into the adjacent mortar matrix.

The near-surface cracks that intersected the formed surface and trend more or less parallel to the length of the core are stained brown, apparently by ferric oxides or organic matter, to depths of 4 to 7 cm. At greater depths, the fracture surfaces are partially coated by white deposits. These deposits are composed of finely divided calcite, ettringite, calcium-alkali-silica gel, and calcium hydroxide. Similar deposits line air voids. No gypsum was found.

Between the fractures, the concrete is moderately hard and compact. The examination gave no evidence of significant bleeding or segregation of the fresh concrete. On fresh fracture produced in the laboratory by breaking the concrete, the cement paste matrix is mottled in appearance and firmness, ranging from vitreous to lack-luster and from very firm to soft. Sound particles of sand, such as quartz grains, are commonly broken across in the more firm portions, but only rarely so in the weaker portions, which predominate in the sample. In the outer part of the section, the cement paste matrix is slightly to moderately carbonated as a result of penetration of carbon dioxide from the atmosphere or in surface waters. Ettringite is present within the cement paste as compact bundles of fibers. Calcium hydroxide is in normal distribution and occurs in small or moderate-sized segregations. The cement is almost completely hydrated. At greater depth, the cement paste matrix is similar except for the absence of carbonation.

The coarse and fine aggregates are like those present in Core No. 1 but the extent of the alkali-silica reaction is less in Core No. 2. In particular, the graywackes do not display evidence of the reaction. Particles of chalcedonic cherts and occasional particles of red siltstones show evidences of the alkali-silica reaction in the form of reaction rims and occasional gel formation, the latter especially in the dark olive green cherts, which typically are totally reacted with formation of calcium-alkali-silica gels. One such particle of green chert, 6.5 by 15 mm in size, had caused formation of radial cracks extending into the surrounding matrix and had released siliceous gel into the cracks.

Core No. 3

The sample included a section of 5-5/8 in. diameter core of portland-cement concrete and a quantity (about 1-1/2 lb.) of rubble of concrete in a bag labelled "#3 outside approx. 1-1/2 - 2". The sample of rubble was composed mainly of very weak, slabby pieces, some of which were bounded at one surface by a lichen-coated exterior and at the inner side by a brown-stained fracture. Other pieces were bounded at all sides by stained fractures. The concrete adjacent to the formed surface was porous and friable to depths of 2 to 5 mm. Similar deterioration was evident along the fracture surfaces. Also, the fracture surfaces were coated by friable material resulting from the complete decomposition and leaching of the matrix. Copious white deposits in voids and along microcracks and aggregate sockets were found to be composed of calcium carbonate, calcium-alkali-silica gel, ettringite, and gypsum.

The section of core was 5-7/8 to 8-1/4 in. long, and was bounded at the outer end by a completely scaled and disintegrated surface. Numerous particles of coarse aggregate had been broken across as a result of the exposure, and several large particles of coarse aggregate had broken away. The inner end of the core is a fresh fracture that had penetrated several particles of coarse aggregate. The outer 1/4 to 1-1/2 in. of the section includes sparse cracks and the mortar matrix is weak, finely porous, slightly friable, and bleached as a result of chemical attack and leaching during service. Additional random cracking extends to a depth of 5 in. from the exterior end of the section.

The main cracks oriented more or less parallel to the length of the core are stained brown by hydrated iron oxides or organic matter to a depth of about 2 in. Other cracks and the main cracks at greater depth are coated by white deposits of calcite, ettringite, calcium-alkali-silica gel, calcium hydroxide, and gypsum. The fractures usually pass around particles of coarse aggregate, but occasional particles are transected.

The cement paste matrix in the concrete adjacent to the exterior surface is soft and includes abundant ettringite both in openings, such as cracks and air voids, and embedded in the matrix. Gypsum is present also in small amounts. The cement paste here is carbonated to varying degree. At greater depth, the concrete is moderately hard, compact, and shows no evidence of significant segregation or bleeding before setting. The cement paste matrix is firm and subvitreous on fresh fractures produced in the laboratory. Such fractures intersect occasional particles of sound fine aggregate, a fact that indicates moderate bond with the aggregate. The cement paste is uncarbonated or slightly carbonated. The cement is almost completely hydrated. Calcium hydroxide is in normal distribution and occurs in small or moderate-sized segregations. Ettringite is present in small amounts in air voids and also occurs in compact bundles within the cement paste matrix.

The coarse and fine aggregates are like those present in Core No. 1. The alkali-silica reaction is only incipiently developed, as in Core No. 2. The reactive aggregate particles are chalcedonic cherts and red siltstones. The graywackes show no evidence of chemical reactions. Except for the green cherts, which are typically totally reacted and converted to calcium-alkali-silica gels, the evidences of the alkali-silica reaction are rim formation and occasional minor internal cracking with development of meager amounts of calcium-alkali-silica gels. The reacted cherts commonly have produced a darkened stain in the adjacent cement paste because of outward permeation of alkali-silica gel.

Core No. 4

The sample was a section of 5-5/8 in. diameter drilled core of portland-cement concrete. The section was 10-1/8 to 10-7/8 in. long. The outer end is a formed surface of the wall that is intact except for slight granular disintegration sufficient to expose the surface of particles of fine aggregate. The surface is stained by lichens. The inner end is a fresh fracture that intersects several particles of coarse aggregate. No cracking was detected in the section except for sparse crazing in the exposed surface. The crazing cracks extend to a depth of about 13 mm and are stained tan.

The concrete is moderately hard, compact, and free from evidence of significant bleeding or segregation before setting. The cement paste adjacent to the outer surface is firm, light gray, and vitreous to subvitreous on fresh fracture produced in the laboratory by breaking the concrete. Sound sand grains commonly are intersected by such fractures, a fact that indicates good quality of bond of the matrix to the aggregate. The cement paste is uncarbonated or slightly carbonated. The cement paste is almost completely hydrated. Calcium hydroxide is in normal distribution and occurs in small or moderate-sized segregations. A trace of ettringite is present within the cement paste matrix and also forms thin films on air voids.

The cement paste and mortar matrix is similar at depth, except that ettringite was not observed.

The coarse and fine aggregates are like those present in Core No. 1. Incipient alkali-silica reaction is present throughout the sample in relation to particles of chalcedonic cherts and red siltstones. The effects of the reaction are confined to rim formation and occasional minor internal cracking and accumulation of calcium-alkali-silica gels.

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PETROGRAPHIC EXAMINATION OF CONCRETE CORE SPECIMENS, LOCK AND DAM NO. 1, MISSISSIPPI RIVER

INTRODUCTION

In accordance with the letter of transmittal dated November 13, 1974, from Mr. E. T. Moore, Project Manager, Harza Engineering Company, Chicago, Illinois, I have examined by petrographic methods ten concrete core specimens that were received by truck freight on November 27, 1974.

The shipment consisted of ten sections of drilled cores of portland cement concrete from Lock and Dam No. 1, Mississippi River. According to the letter of transmittal, five of the specimens are from the Landward Wall, Monolith #12, at distances down from the top of the wall as follows: 7, 15.5, 24, 32.5, and 41 ft. Note that the cores were marked "West Wall, Monolith #12." The other five cores were reported to have been drilled from the opposite landward side of the Center Wall, Monolith #I-13, at the same respective elevations. The cores were marked "East Wall, Monolith #I-13." It was requested that the specimens be examined by petrographic methods to determine the surface condition of the concrete with details regarding the depth of deterioration or to sound concrete, and factors responsible for deterioration observed.

The specimens were examined visually and in detail under the stereoscopic microscope. Each of the specimens was sawed longitudinally through the entire depth in which cracking or other evidences of deterioration could be detected. The sections so obtained were prepared by lapping so as to permit detailed examination of the internal structure of the concrete in an undisturbed condition. Selected portions of the concrete and secondary deposits were examined in immersion oils under the petrographic microscope.

CONCLUSIONS

1. The examination indicates that the concrete represented by the ten samples was originally very similar in composition, degree of consolidation, lack of significant bleeding or segregation of the fresh concrete, and quality and composition of the coarse and fine aggregates. The aggregates are natural sand and gravel, the apparent nominal maximum size being 1-1/2 in. In all instances, the concrete was well cured. As would be expected of concrete of the age of these constructions, the concrete is not air entrained.

2. Several of the cores include varying degrees and kinds of cracking, as follows: (1) Laminar cracking which is cracking more or less parallel to the external surface of the wall, occurring mainly within the mortar matrix but commonly intersecting particles of aggregate, and being sufficiently closely spaced to produce a laminated structure in the affected concrete; (2) longitudinal cracking, that is, cracks that pass into the concrete approximately perpendicular to the outer surface of the wall to depths of 7 or 8-1/4 in.; (3) microcracking spatially related to individual particles of coarse aggregate that were significantly involved in the alkali-silica reaction; and (4) microcracks originating at specific particles of highly porous chert or argillaceous dolomites in the outermost 4-1/2 in. or so of the section, evidently as a result of bursting of the particle as a consequence of freezing while the particle was saturated or nearly saturated by water.

The condition of the specimens in these respects is summarized in the following tabulation:

Summary of Condition of the Specimens

Core No.	Depth of Laminar Cracking, in.	Remarks
1	None	Exterior mortar repair
2	6-15/16	Exterior mortar repair; cracking of Types 3 and 4, above
3	4-1/4	
4	None	Cracking of Type 3, above
5	4	Cracking of Type 3, above
6	None	Cracking of Type 2, above, to depth of 7 in.
7	None	Cracking of Type 2, above, to depth of 8-1/4 in.; also cracking of Types 3 and 4
8	None	
9	4-3/4	
10	11/16	

3. In my opinion consideration should be given to removal of the laminated concrete as shown in Cores 2, 3, 5, 9, and 10 to the indicated depths or to such depths as are indicated by scaling operations at the site. The significance of the longitudinal cracking exhibited by Cores No. 6 and 7 cannot be assessed because of the limited area represented by the cores.

4. The microcracking classified as Types 3 and 4, above, probably is not significant. although it contributes to general deterioration, primarily by increasing the ease with which water can penetrate the concrete and maintain a high degree of saturation, thus increasing susceptibility of the concrete to the effects of freezing and of freezing and thawing.

5. Sulfate attack upon the cement paste matrix of the concrete is indicated by the widespread development of ettringite (high-sulfate calcium sulfoaluminate) in voids, fractures, and openings in aggregate sockets, and also in most of the cores within the cement paste matrix itself. In Cores No. 2, 7, and 9, gypsum (calcium sulfate dihydrate) was found within secondary deposits in voids and cracks, representing a somewhat more extensive exposure to sulfate-bearing waters. However, the examination indicates that sulfate attack is not a primary cause of the observed distress.

6. All of the specimens show evidence of incipient or moderate alkali-silica reaction involving specific lithologic constituents of the coarse and fine aggregate, mainly graywacke sandstones, red quartzose siltstones, olive green cherts, and white chalcedonic cherts. In general, the extent of the reaction and its physical effects are not significant. Microcracking from this cause was found in Cores No. 2, 4, 5, and 7.

7. In my opinion, the primary cause for the distress of the concrete showing laminar cracking is freezing and thawing occurring while the concrete was in a condition of saturation or near-saturation by water. The effects of freezing and thawing would be aggravated by any factors that increase the absorptivity of the concrete, such as microcracking as a consequence of the alkali-silica reaction, sulfate attack on the cement paste, or disruption of highly porous particles of aggregate in the near-surface zone.

8. In all instances, the submitted specimens appear to have penetrated completely any distressed zones in the concrete at the location of the drill hole.

DESCRIPTION OF THE SAMPLES
Landward Wall, Monolith #12

7 Feet from Top of Wall

The specimen was a single section of core, 4-3/16 in. in diameter and 10 to 12 in. long. The outer end was a finished surface that is a mortar repair placed in two applications at widely separated times. The inner end of the specimen is a fresh fracture that intersects many particles of sound coarse aggregate.

The exposed surface is intact and free from cracking. Only superficial disintegration of the cement paste matrix had occurred so as to expose particles of sand in the mortar. The original mortar repair is present in a layer up to 1-1/4 in. thick, whereas the second application is about 9/16 in. thick. The exterior surface of the original mortar layer includes a zone about 5 mm thick in which the cement paste matrix was subjected to leaching prior to application of the second layer. The interfaces between the two mortar layers and between the inner layer and the substrate concrete are moderately well bonded but include numerous voids and weakly cemented areas. The mortars constituting the repairs are hard, sound, compact, and free from deterioration, except for the leached zone at the outer boundary of the original application. When a portion of the mortar facing was broken away in the laboratory, the failure was mainly at the interface or within the substrate concrete.

The substrate concrete is moderately hard, compact, and free from evidence of significant bleeding or segregation. No cracking was found during the examination. On fresh fracture produced by breaking the concrete in the laboratory by means of light blows of a small hammer the cement paste matrix is subvitreous to lack-luster. Only occasional sound particles of fine aggregate are intersected by such fractures, a fact indicating inferior bond of the matrix to the aggregate. The cement paste matrix is uncarbonated or only slightly carbonated as a result of penetration of the hardened concrete by carbon dioxide from the atmosphere. Granules of partially hydrated portland cement are rare; the cement is almost completely hydrated. Calcium hydroxide is in normal distribution and commonly occurs in segregations of moderate size. Air voids are lined by meager, white deposits of ettringite, calcium hydroxide, calcium carbonate, calcium-alkali-silica gel, and alkali-silica gel.

The coarse aggregate is a natural gravel, the apparent nominal maximum size being 1-1/2 in. The main constituents are dolomites, limestones, granitic rocks, granite gneisses, quartzites, diabases and basalts, graywacke sandstones and siltstones, red quartzose siltstones, chalcedonic cherts, and red or pink felsites. The fine aggregate is a natural sand. The coarse fractions are similar in composition to the gravel. The finer fractions are highly quartzose and feldspathic. No deleterious cement-aggregate reactions were indicated by the examination. Particles of white cherts common bear a thin, peripheral rim and, in some instances, alkali-silica gel has permeated into the adjacent cement paste. However, no cracking was found in relation to these occurrences.

Core No. 2, 15.5 Feet From Top of Wall

The specimen was a single section of core, 4-3/16 in. in diameter and 12 to 12-1/2 in. long. The outer end was a finished surface that is a mortar repair placed in a single application. The inner end of the specimen is a fresh fracture that intersects numerous particles of sound coarse aggregate.

The mortar facing is 7/16 to 13/16 in. thick and was placed against an irregular surface of the substrate concrete. The mortar layer is very well bonded to the concrete; when an attempt was made to remove the mortar layer, the fracture occurred indiscriminately in the mortar or the concrete, rather than at the interface. The mortar is hard, sound, and free from deterioration. The exterior surface itself shows only granular disintegration sufficient to expose particles of sand, except for sparse pits created by breakdown of highly porous particles of coarse sand in the mortar.

Laminar cracking roughly parallel to the exterior surface is present in the outer 6-15/16 in. of the specimen, being most common in the outer 2 in. A second zone of cracking occurs at a depth of 2-1/2 to 3-1/4 in., and a third to 6-3/8 to 6-15/16 in. Voids and cavities immediately below the mortar facing include copious amounts of white to colorless alkalic silica gel, calcium-alkali-silica gel, calcium hydroxide, ettringite, gypsum, and finely divided calcium carbonate. The cracks at depth are partially lined by extremely finely crystalline ettringite, calcium hydroxide, calcium carbonate, and trace amounts of gypsum, A particle of highly porous, chalcedonic chert, 9/16 in. in diameter, lying at a depth of 4-1/2 in. was the source of radiate fractures passing into the adjacent mortar matrix, apparently as a result of pressure produced during freezing of the saturated particle.

The aggregate is like that in the previously-described sample. Evidencesof the alkali-silica reaction are well developed in relation to particles of olive-green cherts, chalcedonic white cherts, red quartzose siltstones, and dark gray graywacke sandstones. The evidences are deposits of alkalic silica gel and calcium-alkali-silica gel, darkened reaction rims, internal cracking of the aggregate particles, and occasional cracks that pass from the particle into the adjacent matrix. Such external cracking resulting from the alkali-silica reaction is best developed at particles of olive green chert of larger size, but external cracking also was observed in relation to graywacke sandstones.

In the outer part of the core where cracking is present, the concrete is moderately hard to relatively weak. The concrete is compact and shows no evidence of significant bleeding or segregation. On fresh fracture produced in the laboratory, the cement paste matrix is lack-luster, uncarbonated to slightly carbonated, and sound particles of sand are only sparsely intersected. The cement is essentially completely hydrated. Calcium hydroxide is present in segregations of moderate size. Ettringite is present within the matrix as well as in voids and other openings. At greater depth, the concrete is moderately hard and the cement paste matrix is subvitreous to lack-luster in appearance on fresh fracture. Sound sand grains are intersected more frequently by such fractures produced in the laboratory. Deposits of ettringite, calcium hydroxide, and calcium carbonate occur in air voids throughout the length of the specimen. Also, ettringite is visible in the cement paste matrix throughout the depth penetrated by the core.

Core No. 3, 24 Feet From Top of Wall

The specimen was a drilled core, 4-3/16 in. in diameter, that was received in one piece, 11 to 12 in. long. The outer end is the exterior, formed surface of the concrete. The inner end is a new fracture produced during taking of the core; the fracture intersected several sound particles of coarse aggregate. The formed surface is etched as a result of the service exposure so as to reveal the outer surface of particles of coarse aggregate, and occasional particles of coarse aggregate had broken away.

The outer 4-1/4 in. of the core includes a large number of narrow, discontinuous cracks that more or less parallel the exposed surface, producing an laminar structure, especially in the outer 1-3/4 to 2-1/2 in. The cracking is more widely spaced in the remaining interval to a depth of 4-1/4 in.

The concrete in the cracked section is easily broken away by light blows of a small hammer. The surfaces of the cracks are partially coated by very meager amounts of white deposits composed of extremely finely crystalline ettringite, calcium hydroxide, and calcium carbonate together with small amounts of calcium-alkali-silica gel and alkalic silica gel. The cracks intersect occasional particles of porous or fractured coarse aggregate, including dolomites, cherts, and granite.

The concrete between the cracks and the intact concrete at greater depth is moderately hard, compact, and shows no evidence of significant bleeding or segregation. The cement paste matrix is subvitreous to lack-luster in appearance on fresh fracture produced in the laboratory; such fractures intersect sparse particles of sound fine aggregate, although the proportion of such intersection increases with depth from the surface. The cement paste is uncarbonated or slightly carbonated. Calcium hydroxide occurs in segregations of moderate size. Ettringite occurs in air voids and sparsely in visible form within the cement paste matrix throughout the length of the specimen.

The aggregate is like that present in the previously-described specimens. The alkali-silica reaction is only incipiently developed, without apparent distress of the concrete. Occasional, darkened rims are present on particles of white chalcedonic chert and red quartzose siltstones.

Core No. 4, 32.5 Feet From Top of Wall

The specimen was a single section of 4-3/16 in. diameter core, 11 to 11-1/2 in. long. The outer end was the formed surface of the concrete. The inner end was an irregular fracture produced as the core was secured. The inner end intersected several particles of sound coarse aggregate. The exposed surface had been etched by the service exposure sufficiently to reveal particles of coarse aggregate and some unsound aggregate particles had disintegrated completely, leaving pits up to 3/8 in. deep.

The section includes no laminar cracking. A microcrack originating in a pebble of red quartzose siltstone about 3/4 in. in width and lying at a depth of about 2 in. extends a total distance of 1-3/4 in. along the length of the core, penetrating the adjacent mortar and other aggregate particles. The crack is the result of the alkali-silica reaction. Particles of olive green chert in the fine gravel and coarse sand fractions are softened throughout, and particles of white chalcedonic cherts and graywackes show peripheral rims; the cement paste adjacent to the particles of white chert commonly is stained by alkalic silica gel.

Except for a superficial, highly carbonated zone about 3 mm thick at the exposed surface, in which the cement paste is softened, white, and lack-luster, the cement paste matrix in the concrete is firm and vitreous to subvitreous on fresh fracture. Sound particles of sand commonly are intersected when the concrete is broken. Air voids are sparse and empty except for occasional, meager deposits of ettringite, calcium hydroxide, and calcium carbonate; such deposits are present throughout the length of the core. No ettringite was found in the carbonated zone at the surface, but ettringite is visible within the cement paste matrix in the underlying concrete, at least to a depth of 3-3/4 in. Ettringite is not present in visible development in the cement paste at the inner end of the core. The cement is almost completely hydrated. The concrete beneath the superficial zone is uncarbonated or slightly carbonated. Calcium hydroxide is present in segregations of moderate size.

The concrete as a whole is moderately hard, compact, and free from evidences of bleeding and segregation.

Core No. 5, 41 Feet From Top of Wall

The specimen was a drilled core, 4-3/16 in. in diameter, that was received in two sections separated along an irregular fracture. The overall length was 11-1/8 to 12 in. The outer section was 6-1/16 in. long. The separating fracture and the fracture forming the inner end of the specimen were produced when the core was secured; each of these fractures penetrated several sound particles of coarse aggregate. The outer end is a formed surface of the concrete; the surface had been etched during service sufficiently to expose particles of coarse sand.

Widely spaced, laminar cracking is present in the core to a depth of 4 in. The cracks trend more or less parallel to the formed surface. They are 1 to 1-1/2 in. apart and pass around sound particles of coarse aggregate. The cracks and air voids are lined by very scanty, white, very finely crystalline deposits of ettringite, calcium hydroxide, and calcium carbonate, together with small amounts of calcium-alkali silica gel. Such deposits occur in all voids and openings in pebble sockets throughout the length of the core.

The concrete is moderately hard, compact, and free from evidence of significant bleeding or segregation. The cement paste is vitreous to subvitreous on fresh fracture, and intersection of sound particles of sand by such new fractures is common. The cement paste is uncarbonated or slightly carbonated. The cement is almost completely hydrated. Calcium hydroxide is present in segregations of moderate size. Ettringite is visible in the cement paste matrix throughout the length of the core.

The aggregate is like that described above. Alkali-silica reaction is incipiently developed. Occasional particles of the olive green cherts are totally digested. Darkened rims are common on particles of white chalcedonic cherts. Graywackes and red quartzose siltstones commonly display darkened rims, minor internal cracking, and small accumulations of calcium-alkali silica gel. Subradiate microcracks into the adjacent cement paste is present in association with larger particles of the olive green cherts.

Center Wall, Monolith #I-13

Core No. 6, 7 Feet From Top of Wall

The specimen is a section of 4-3/16 in. diameter drilled core that is 11-3/16 to 12 in. long. The outer end is the formed surface of the concrete that had been etched during service sufficiently to reveal particles of sand. The inner end was an irregular, new fracture produced during the taking of the core; the fracture intersects several particles of sound coarse aggregate.

The external surface displays a distinct pattern cracking. Several of the cracks could be traced into the concrete for several inches, the maximum distance being 7 in. Two such cracks were present in a diametral cross section of the core. The outer 1-1/2 in. of the cracks are stained brown by organic matter and iron oxides. At greater depth, the cracks are coated by scanty amounts of very finely crystalline ettringite, calcium hydroxide, and calcium carbonate, commonly with small amounts of calcium-alkali silica gel. No laminar cracking parallel to the exterior surface is present.

The concrete is moderately hard, compact, and free from indications of significant bleeding or segregation. On fresh fracture produced in the laboratory, the cement paste is subvitreous to lack-luster in appearance; only sparse sound sand grains are intersected, a fact that indicates inferior bond of the matrix to the aggregate. The cement is almost completely hydrated. The cement paste is uncarbonated or slightly carbonated. Calcium hydroxide is present in segregations of moderate size. Ettringite is present in very small amounts of voids and in the cement paste in visible form throughout the length of the core.

The aggregate is like that present in accompanying specimens from both structures. Only incipient alkali-silica reaction is indicated. Darkened rims occur on particles of white chalcedonic cherts and particles of olive green cherts are totally reacted. However, no cracking of the matrix was found in association with these occurrences.

Core No. 7, 15 Feet From Top of Wall

The specimen was a section of 4-3/16 in. diameter core, 10-7/8 to 11-1/4 in. long. The outer end is the formed surface of the concrete that had been etched sufficiently during service to expose particles of sand. The inner end is a fresh fracture along which the core was broken away from the concrete in place. The inner surface mainly passed around, rather than through particles of coarse aggregate along the fracture.

No laminar cracking is present in the specimen. However, a longitudinal crack occurring at one side of the core could be traced from the exterior surface to a depth of 8-1/4 in. The crack transected both the mortar matrix and particles of aggregate. The fracture surface was stained brown by organic matter and iron oxides to a depth of 6 in. Throughout the depth, the crack is partially coated by meager white deposits of very finely crystalline ettringite, calcium hydroxide, calcium carbonate, and gypsum (trace amounts), together with local occurrences of calcium-alkali silica gel adjacent to reacting particles of aggregate. A large pebble of tan, argillaceous dolomite (9/16 in. thick by 1-1/4 in. in diameter) lying 1-1/4 to 2-1/4 in. from the exterior surface was disrupted by numerous internal cracks that passed out into the adjacent mortar. A buff colored pebble of highly porous, silty dolomite, 1-1/4 in. in diameter lying adjacent to the formed surface also included numerous open cracks that passed into the matrix.

The concrete is hard, compact, and free from indications of significant bleeding or segregation. On fresh fracture produced in the laboratory, the cement paste matrix is vitreous to subvitreous and a high proportion of sound sand grains along the fracture are broken across, a fact that indicates good quality of bond of the matrix to the aggregate. The cement is almost completely hydrated. The cement paste is uncarbonated or only slightly carbonated. Calcium hydroxide is present in small segregations, as is typical of concrete of relatively low water-cement ratio. Trace amounts of ettringite are present in visible form in the cement paste. Very finely crystalline ettringite, calcium hydroxide, and calcium carbonate are present in air voids throughout the length of the specimen.

The aggregate is like that in the accompanying cores. In the main, only incipient alkali-silica reaction is indicated. However, an advanced degree of the alkali-silica reaction was found in a pebble of graywacke sandstone about 3/4 in. in diameter and lying at a depth of 2-1/8 in. The pebble included several microcracks and was transected by the major longitudinal crack described above. A small amount of calcium-alkali-silica gel was present in the microcracks.

Core No. 8, 24 Feet From Top of Wall

The specimen was a section of 4-3/16 in. diameter core that was 10-1/4 to 10-7/8 in. long. The exterior surface is the formed surface of the wall. The concrete had been etched sufficiently to reveal particles of fine aggregate. The inner end is a fresh fracture produced when the core was taken; the fracture surface intersected several particles of sound coarse aggregate.

The core is free from laminar or longitudinal cracking. The concrete is hard, compact, and free from indications of segregation. Moderate bleeding is shown by separations adjacent to particles of coarse aggregate. On fresh fracture in the laboratory, the cement paste varies from vitreous to subvitreous to lack-luster; intersection of sound particles of sand by such fracturing is sparse to common in the various portions of the matrix. Ettringite, calcium hydroxide, and calcium carbonate are common as meager deposits in air voids and separations adjacent to aggregate particles throughout the length of the specimen. The cement is almost completely hydrated. The cement paste is uncarbonated or only slightly carbonated. Calcium hydroxide is present in moderate to large segregations, as is typical of concrete of variable and relatively high water-cement ratio. Ettringite is visible in the cement paste in small amounts throughout the length of the specimen.

The aggregate is similar in composition to that present in the accompanying samples. Only incipient alkali-silica reaction is indicated. Darkened rims are present on particles of white chalcedonic cherts. No deleterious effects of the alkali-silica reaction were observed in the specimen.

Core No. 9, 32.5 Feet From Top of Wall

The specimen was a section of 4-3/16 in. diameter drilled core that was received in three pieces. The overall length was 11-1/8 to 11-7/8 in. The outer section was 1 to 1-5/16 in. long and included numerous, laminar fractures more or less parallel to the external surface. The second separation lies at a depth of 6-3/8 to 7 in. Laminar cracking is frequent in the interval from 2 to 2-1/2 in. The outer separation is an old, pre-existing crack. More widely spaced laminar cracking is present to a depth of 4-3/4 in. The two inner separations were produced during the taking of the core.

The exterior surface is the formed surface of the concrete as placed. The surface is intact except for granular disintegration of the cement paste matrix such that particles of coarse sand are exposed. The inner end of the outer section is partially coated by very meager, white deposits. This section includes closely spaced laminar cracks that transect both the mortar matrix and particles of porous coarse aggregate. The outermost crack occurs at a depth of 1/4 to 3/8 in. The outermost portion of the section could be pulled away by the hands alone. The fractures are coated by a dull film of white, secondary deposits that are composed of extremely finely crystalline ettringite, calcium hydroxide, and calcium carbonate with trace amounts of gypsum. Also present are sparse amounts of calcium-alkali-silica gel and alkali-silica gel resulting from the alkali-aggregate reaction.

The concrete is weak to moderately hard, compact as placed, and free from indications of significant bleeding or segregation. At the outer end of the core, the cement paste is subvitreous to lack-luster in appearance on fresh fracture in the laboratory; sound sand grains are rarely intersected because of the poor bond of the matrix to the aggregate. At depth, the cement paste matrix is subvitreous in appearance on fresh fracture and sound particles of sand commonly are broken across. The cement is almost completely hydrated. Calcium hydroxide is present in small segregations in the matrix. Ettringite is well developed within the cement paste matrix in the outer portion of the core but none was found in the inner portion.

Air voids throughout the section contain meager coatings of white deposits composed of finely crystalline ettringite, calcium hydroxide, calcium carbonate, and traces of gypsum.

The aggregate is like that present in the accompanying cores. Only meager evidence of the alkali-silica reaction was found except for well developed internal fracturing and gel formation in a particle of red quartzose siltstone in the coarse aggregate, softening of sparse particles of the olive green chert, and rim formation on particles of white chalcedonic chert and graywacke sandstones. Some particles of the affected white cherts are surrounded by staining of the cement paste by outward permeation of alkalic silica gel.

Core No. 10, 41 Feet From Top of Wall

The specimen was a section of 4-3/16 in. diameter drilled core that was 10 to 10-7/8 in. long. The outer end was the formed surface of the concrete except that about three fourths of the area had been removed by scaling and general disintegration of the near-surface concrete to depth up to about 3/8 in. The inner end is a fresh fracture produced during the taking of the sample. Frequent cross-fracture of the coarse aggregate occurred on the inner surface. The outer 1/16 to 11/16 in. of the section is relatively weak and fractured internally and is bounded against the substrate concrete by an irregular fracture that transects both the mortar matrix and particles of aggregate. The outermost portion includes conspicuous white deposits and brown staining in voids, fractures, and aggregate sockets. The white deposits are extremely thin and very finely crystalline ettringite, calcium hydroxide, and calcium carbonate, with trace amounts of gypsum. In this zone, the cement paste matrix is highly carbonated; ettringite is present in fibrous bundles in the cement paste.

The concrete below the superficial zone is moderately hard, compact, and free from evidences of significant bleeding or segregation. The cement paste matrix on fresh fracture is vitreous to subvitreous in appearance and sound sand grains commonly are broken across. The cement is almost completely hydrated. Calcium hydroxide is present in small or moderate sized segregations. Ettringite is visible in small amounts in the cement paste throughout the length of the core. Meager deposits of ettringite, calcium hydroxide, and calcium carbonate are present in air voids throughout the length of the core.

The aggregate is like that present in the accompanying cores. The alkali-silica reaction is only incipiently developed. Minor rim formation is present on white chalcedonic cherts and several particles of olive green cherts are completely digested but without development of external cracking.

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