PARKER DAM CONCRETE CORE INVESTIGATIONS

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16. ABSTRACT

This report is a review and analysis of physical property tests and petrographic examinations of concrete cores from Parker Dam. Cores were taken from the dam in 1938, 1940-41, 1943, 1945, 1949, 1956, and 1980. Test data from 1980 cores are reported and compared to earlier core data. The concrete from Parker Dam was, in most cases, stronger in 1980 than when completed in 1938. There were apparent strength reductions in the top portions of the dam from 1938 to 1956, with a rebound in strength since that time.

Evidence of alkali-aggregate reaction was found throughout the dam as substantiated by the petrographic analysis. Further evidence was the reduction in modulus of elasticity at all elevations in Parker Dam, although a rebound in modulus of elasticity appears to occur in recent years. The alkali-aggregate reaction is most severe in the upper portions of the dam, resulting in a higher incidence of disbonded construction joints.

Assuming that most of the reactive silica and alkalies have been consumed, very little future deterioration will take place as the result of alkali-aggregate reaction.

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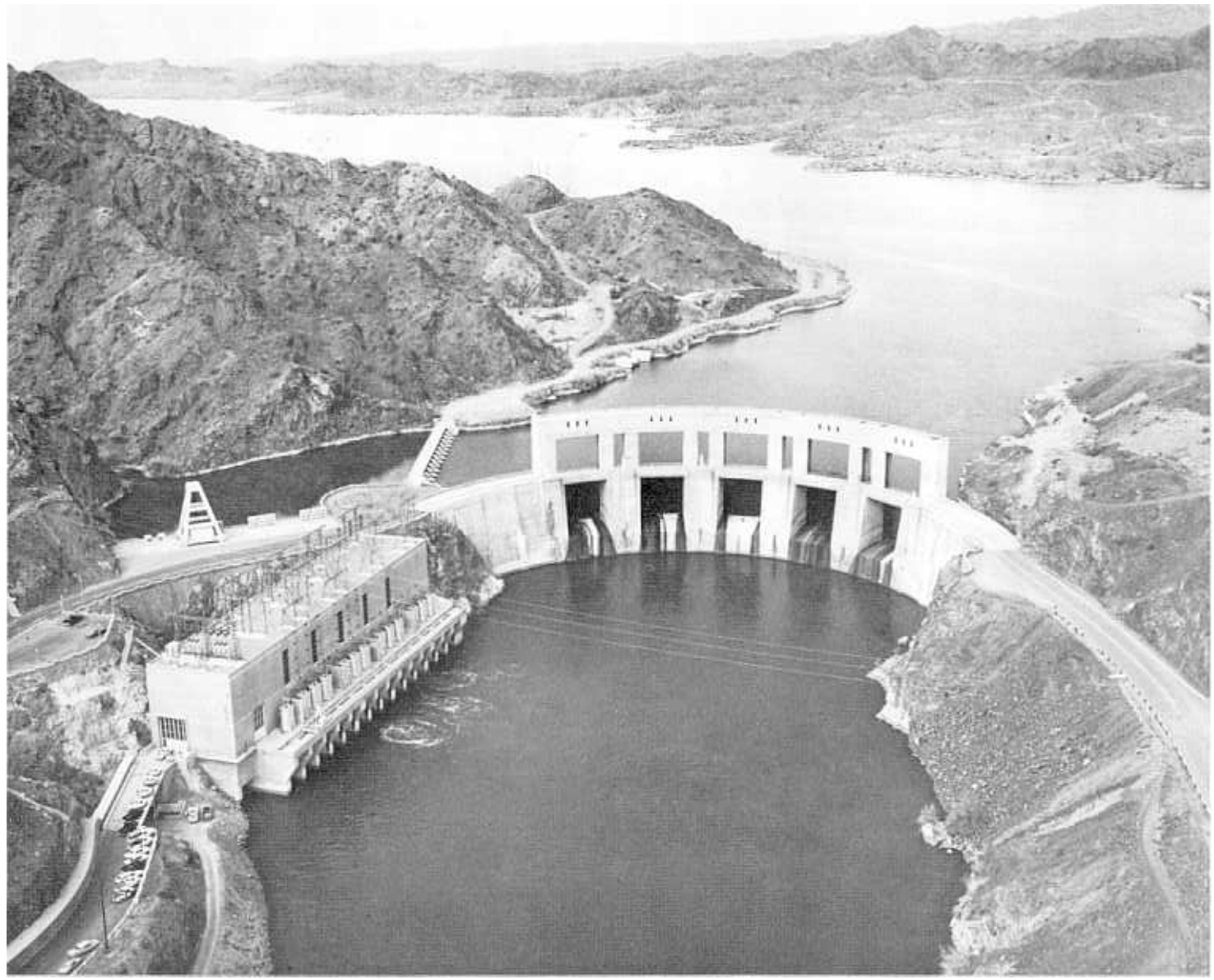
As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.



Frontispiece: Parker Dam, P80

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INTRODUCTION

Parker Dam is a concrete structure about 100 meters (325 feet) high and is located 250 kilometers (155 miles) below Hoover Dam on the Colorado River. The bottom portion of the dam, below the spillways, is an arch structure, and the upper portion is a series of gravity sections between the spillway gates.

The dam was the first USBR (Bureau of Reclamation) structure identified as having alkali-aggregate reaction. The dam was built using aggregate from the confluence of the Bill Williams and Colorado Rivers. This aggregate has proven to be very reactive with the high-alkali cement used, but the dam was built before problems resulting from this combination of materials were identified. The combination of high-alkali cement and reactive aggregate led to expansion and cracking within two years after completion of the dam, and, for this reason, it has been kept under very close surveillance.

Cores have been extracted from the dam several times through the years to monitor the condition of the concrete in the dam. The first set of cores was extracted in 1938 [1]* to ascertain the extent of cracking caused by grouting operations. At that time the dam had not cracked due to alkali-aggregate reaction. Following the onset of visible cracking, cores have been periodically extracted to monitor the progress of alkali-aggregate reaction. Cores were extracted in 1940-41 [1], 1943 [1], 1945 [1], 1949 [2], 1956 [3], 1964 [4], and 1980. Cores were extracted from the powerplant and the forebay structure in 1940-41, 1949, and 1956. The area in the powerplant in which a low-alkali cement was used is not experiencing alkali-aggregate reaction [3].

This core study is the result of recommendation 79-SOD2-B from the 1980 SEED (Safety Evaluation of Existing Dams) report on Parker Dam [5]. The 1980 cores are all from the dam and, therefore, analysis is made only of concrete from the dam. This report includes all of the data for the 1980 investigations and makes reference to or includes comparable data from previous studies. Part of the data from previous years were not comparable. For example, part of the data from 1938 included test results for cores that were allowed to dry before testing. These data are not comparable to the test results from other years in which the cores were saturated or kept moist until testing. Also, some cores from 1940-41 were only 75-mm (3-in) diameter, which were not adequate for large maximum size aggregate concrete. This report includes only test results for 150-mm (6-in) and 250-mm (10-in) diameter cores.

* Numbers in brackets refer to references listed at the end of the text.

CONCLUSIONS

1. Though evidence of alkali-aggregate reaction is present throughout the dam, the average compressive strength is now greater than it was in 1938.

2. The compressive strength of concrete near the top of the dam and spillways dropped during the first 18 years, and then apparently rebounded to the initial strength of 1938. Isolated areas exist, usually near the surfaces of the upper portion of the dam, where the strength is less than the initial strength in 1938.

3. The modulus of elasticity of concrete has been reduced, probably due to alkali-aggregate reaction throughout the dam. The modulus of elasticity is about half that of similar strength concrete which has not experienced alkali-aggregate reaction.

4. Poisson's ratio test results are very erratic, varying from a low of 0.03 to a high of 0.33. The results appear to vary much more than those of Stewart Mountain Dam which has also experienced deleterious alkali-aggregate reaction [6].

5. The condition of construction joints indicates greater deterioration in the upper (gravity) portion of the dam than in the lower (arch) portion. Only about 18 percent of the construction joints are intact near the top of the dam, whereas about 60 percent are intact in the lower portion.

6. Good correlation occurs between compressive strength reduction and extent of petrographically determined alkali-aggregate reaction. Concrete having the most alkali-aggregate reaction generally has the lowest strength.

7. The apparent rebound in compressive strength and modulus of elasticity since 1956 may indicate that alkali-aggregate reaction has been reduced. The reactive alkalies and/or silica may have been consumed by 1956 or perhaps only a small quantity

remains. Should the compressive strength and elasticity remain at their present levels, it is assumed that Parker Dam will experience no further deterioration due to alkali-aggregate reaction.

8. Should the water level drop, either upstream or downstream of the dam, exposing it to higher ambient temperatures, the small amount of alkali-aggregate reaction that could still occur might be intensified. However, the magnitude of reaction would be minimal.

9. To verify conclusions 7 and 8, tests of expansion potential of concrete from lower portions in the dam should be conducted at less than 100 percent relative humidity and at temperatures similar to ambient summer conditions near Parker Dam.

10. A concrete core study of Parker Dam should be made in approximately 10 years to continue monitoring trends in compressive strength and modulus of elasticity.

CONCRETE PHYSICAL PROPERTIES

Summaries of results of tests on the 1980 cores are presented in tables 1, 2, and 3. The locations of cores taken from the dam through the years are shown in figure 1.

Compressive Strength

The 1936 concrete mix investigation for Parker Dam recommended a 150-mm (6-in) maximum size aggregate mass concrete mix, having an average W/C (water to cement) ratio of 0.57 [7]. The maximum allowable W/C ratio was 0.60. The laboratory mix investigation indicated an average compressive strength for a wet screened 150- by 300-mm (6- by 12-in) cylinder to be 28.7 MPa (4160 lb/in^2) after 28 days.

The test cylinders corresponding to the concrete cores from 1938 [1] had an average W/C ratio of 0.57 and an average compressive strength of 26.6 MPa (3860 lb/in^2). The concrete in place is very similar to that recommended by the laboratory investigation discussed above.

The average strength of the saturated concrete cores from the 1938 study was 25.6 MPa (3720 lb/in^2). This strength was assumed to be the initial strength of the concrete for this investigation. No evidence of cracking due to alkali-aggregate reaction was found when the first cores were obtained in 1938, soon after completion of the dam.

The compressive strength of the concrete in Parker Dam has changed through the years, but the change has not been uniform throughout the dam. The strength of concrete in the lower elevations and most of the upper elevations has increased with time. For example, the average compressive strength near the top of the dam for 1980 was 28.8 MPa (4180 lb/in^2), and near the bottom of the dam the average strength was 37.7 MPa (5460 lb/in^2). However, there was a strength reduction in the concrete near the upper surfaces during the first 18 years, with a recent rebound in strength. The overall effect has been minimal strength differences between 1938 and 1980. The compressive strength near the top of the dam dropped to a low of approximately 20.7 MPa (3000 lb/in^2) between 1945 and 1949 (fig. 2).

Figure 2 is a plot of the compressive strength versus age (as listed in table 2) and shows the strength trend for concrete at various elevations in the dam. Only those ages and elevations having at least three test results to develop an average are plotted. The plotted data are the "average" figures in table 2.

The strengths of the 250-mm diameter cores extracted from the dam were converted to equivalent 150-mm diameter core strengths as recorded in table 2. The 250-mm core was assumed to have 94 percent of the strength of a 150-mm core. This factor was taken from the Bureau of Reclamation Concrete Manual, figure 227, page 574 [8].

As shown by the trends in figure 2, only the concrete near the surface has experienced any decrease in strength over the years, and that concrete has since appeared to rebound in strength similar to the initial condition in 1938. Although much of the concrete at lower elevations has not experienced a strength reduction, this does not mean that no alkali-aggregate reaction occurred. Internal deterioration can be indicated by a decrease in the modulus of elasticity [9].

The results for concrete from elevations 114- to 122-m (375- to 400-ft) are plotted as a broken line on figure 2. This curve is unique because of its strength history. An increase in strength from 1938 to 1945 was found, as expected. However, after 1945, the concrete at this elevation began to

lose strength. This behavior might be explained by the concrete's history. The concrete at this elevation is near the top of the spillways. Water was released over the spillways during construction of the powerplant [5] and, therefore, the spillways were under water for four years. Very limited use of the spillways has been made since that time, allowing the concrete near the top of the spillways to dry.

The spillway surfaces did not experience cracking as quickly as the concrete on the top of the dam. This fact is indicated by the following statement made concerning an inspection in 1940 [10]:

> "18. Most of Parker Dam proper is below reservoir water and tail-water surfaces and is therefore protected from exposure. There is indication that cracking has not developed in such protected portions of the structure."

Because cracking occurred on the top of the dam and not in lower areas, it was felt that the cracking might be aggravated by drying [10]:

> "10. There is suspicious indication that the cracking is caused by some condition of unsoundness, inherently present in the concrete which is aggravated and advanced by extreme conditions of drying."

To investigate the concrete in a saturated condition which was not yet cracked to the same extent as the concrete on the top of the dam, cores were taken from the surface of spillway No. 3 in 1940-41. This delayed cracking agrees with results of recent research. Hobbs [11] reports that in the case of medium to high W/C ratio mortars (ratios in excess of 0.53), cracking is delayed in specimens continually immersed in water when compared with specimens stored in 100 percent relative humidity but not immersed. As discussed earlier, the W/C ratios in Parker Dam were in excess of 0.53, averaging about 0.57.

The concrete in the spillway appears to have followed the expected trend, increasing in strength from 1938 to 1945 as shown by the broken line in figure 2. The spillway concrete initially was under water and gained strength. Then, after four years' use, the concrete at the top of the spillways experienced drying, rapid expansion, and cracking similar to the initial performance of concrete on the top of the dam. The strength has since apparently rebounded as did the concrete on top of the dam (fig. 2).

Elasticity

For normal portland cement concrete, the modulus of elasticity is related to compressive strength. Concretes of higher strengths usually have higher values of modulus of elasticity [12]. The modulus of elasticity was plotted versus compressive strength for the 1980 concrete core study in figure 3. The plotted points were the maximum stress levels tested as shown in table 1. Both the chord modulus and the tangential modulus are shown in table 1, and the chord modulus was plotted in figure 3.

A comparison of the elasticity in 1980 versus the elasticity in 1938 can be made. The average cylinder strength for the 1936 mix investigation [7] was 28.7 MPa (4160 lb/in^2) for an average W/C ratio of 0.57. The average modulus of elasticity for that investigation was 26.9 GPa (3.90×10^6 lb/in^2). This relates very well to the elasticity of the 1938 cores of 25.5 GPa (3.70×10^6 lb/in^2). The 1938 cores had an average compressive strength of 25.3 MPa (3670 lb/in^2). The average 1980 modulus of elasticity is about half that of 1938, even though the compressive strength has increased. For example, the average compression strength for elevations 46- to 91-m (150- to 300-ft) is 37.7 MPa (5460 lb/in^2), table 2. Using this strength value in figure 3 leads to a predicted modulus for 1980 of 19.9 GPa (2.89×10^6 lb/in^2) for the corresponding elevations. For comparison, Shasta Dam concrete with a compressive strength of 35.4 MPa (5140 lb/in^2) had an elastic modulus of 39.3 GPa (5.70×10^6 lb/in^2) [13]; and 10-year-old exterior concrete from Flaming Gorge Dam had a core compressive strength of 32.2 MPa (4670 lb/in^2) with a corresponding elastic modulus of 34.5 GPa (5.0×10^6 lb/in^2) [14].

As shown above, the modulus of elasticity of concrete at lower elevations of Parker Dam is about half of the value found in other USBR dams. Consequently, even though the strengths have increased and are very good at lower elevations, it appears that the alkali-aggregate reaction has lowered the modulus of elasticity.

The decrease in elastic modulus preceded a loss in strength in the upper surfaces of the dam. For example, the compressive strength of the concrete in the top of spillway No. 3 increased from 25.6 MPa (3720 lb/in^2) in 1938 to 30.8 MPa (4470 lb/in^2) in 1943. During this same period, the modulus of elasticity decreased from 25.5 GPa (3.70×10^6 lb/in^2) to 13.4 GPa (1.95×10^6 lb/in^2).

However, a corresponding drop in strength did not begin until 1949, dropping to a low in 1956. The elasticity continued to drop from 1943 to a low of 11.2 GPa (1.63×10^6 lb/in^2) in 1956. Since 1956, a slight rebound in modulus of elasticity has occurred which corresponds to a strength increase. The average modulus of elasticity is 13.5 GPa (1.96×10^6 lb/in^2) for those cores in the 1980 study from the top of the spillways at elevations 114- to 122-m (375- to 400-ft).

The 1936 mix investigation indicated a Poisson's ratio of 0.17 for 28 days' age wet-screened cylinders. The average Poisson's ratio for the 1938 cores was 0.15. The average ratio in 1980 was 0.16. There does not appear to be any change in this ratio over the years; however, the 1980 test results showed large variations. The ratio varied from a low of 0.03 to a high of 0.33, a higher variance than found for Stewart Mountain Dam [6] which has also experienced deterioration due to alkali-aggregate attack. The difference might possibly be due to more microcracking in the structure.

Break Bond and Sliding Friction

Selected specimens were subjected to a direct shear loading condition, generally referred to as a "break bond" test, and others to only "sliding friction" tests. All of the test specimens contained a construction joint. The results of these tests are shown in table 3 and are summarized by a linear regression analysis for each specimen. Values for cohesion, friction angle phi, and the corresponding linear regression equation (shear stress versus normal stress) are shown in the table. A linear regression of the combined data is shown in the table and in figure 4. The linear regression line, the lower line in figure 4, has a correlation coefficient of 0.91 for 195 points for sliding friction. The upper line has a correlation coefficient of 0.76 for 7 points for break bond.

As shown by the results of break bond tests, some of the construction joints in the dam are intact. The 1980 cores intersected 113 joints, 33 of which were intact. Table 4 is a summary of the joint conditions by elevation. A higher incidence of intact joints was found in the lower portions of the dam (60 percent) than in the upper portion (18 percent). The low incidence of intact joints in the upper portion is significant because this area of the dam is a gravity section rather than an arch section. It is possible that the internal expansive pressure within the dam caused by alkali-aggregte reaction has caused movement in the gravity section where there is less resistance to movement than in the arch section. This should be verified by measurement.

The higher incidence of intact joints in the lower portions of the dam possibly indicates less movement due to alkali-aggregate reaction. This assumption seems reasonable since this concrete is under greater restraint than that near the top.

Petrographic Analysis

A petrographic analysis was performed on various core specimens from 1980 drill holes 1, 2, and 4. The complete petrographic report is included as an appendix, and data are summarized in attachment 4 of that report. The compressive strength was compared to the degree of alkali-aggregate reaction determined by petrographic methods. A linear regression analysis of these data was made by assigning the degree of reaction a number. The numbers are as follows: 5—high, 4—moderately high, 3—moderate, 2—moderately low, and 1—low. Comparing these numbers to the compressive strengths, a correlation coefficient of 0.70 was found which reflects a good correlation. The higher the degree of reaction, the lower the resulting compressive strength.

Alkali-aggregate Reaction

Alkali-aggregate reaction, which in this case is more properly designated as alkali-silica reaction, has caused severe cracking in Parker Dam. This phenomenon is complex, and several theories have been advanced to explain the reactions that take place. The reactive portion of the aggregate, the silica, reacts with alkalies in the cement (potassium and sodium) and also with calcium hydroxide, a product of cement hydration. The reaction product formed is either a nonexpansive calcium-alkali-silica complex, or an alkali-silica complex which can expand by imbibition of water [15]. Both of these reaction products are solids and the one that forms is dependent upon many factors. When a low-alkali cement is used, the final product has a high calcium portion which produces the nonexpansive calcium-alkali-silica complex. In high alkali systems, the solubility of calcium is greatly reduced; a high alkali concentration in the pore water then results in the alkali-silica complex, which is expansive.

One theory advanced to explain the mechanism of expansion is that of Hansen [16] which attributes the expansion to osmotic pressures. The cement paste around a reactive particle acts as a semi-permeable membrane which allows alkali hydroxides and water to pass in, but prevents the complex alkali-silica products from passing out. An osmotic cell is then set up. Pressures of over 3.5 MPa (500 lb/in^2) can be developed [17], and may exceed tensile strength of the concrete.

The above description of alkali-silica reaction can be used to explain the test results for Parker Dam. The cracking is greatest at the top of the dam. The concrete in this area does not have the external restraints which are imposed on the concrete deep in the dam. The concrete deep in the dam is confined by the static load of the concrete and the force of the reservoir. Assuming that the expansion is caused by osmotic pressures from alkali-aggregate reactions, larger pressures would be required at lower elevations to cause damage.

In addition, the drier condition of the concrete near the top of the dam may lead to higher pressures. Hobbs [10] theorizes that the hydroxyl ion (alkali) concentration in the pore water is higher. If a sufficient amount of water is available to establish osmotic pressure, then the alkali concentration is determined by the amount of water; i.e., a lesser amount of water will cause a higher alkali concentration. In illustration, if in a glass we put a known amount of alkalies and on the glass we put a line indicating the amount of water needed to establish osmotic pressure, at this level the alkali concentration would be at its maximum. Further additions of water would dilute the solution. Higher concentration of alkalies leads to higher production of expansive alkali-silica complexes and higher osmotic pressures.

Lower in the dam, the concrete has a higher moisture concentration due to the water pressures of the reservoir forcing water into the concrete. This higher moisture content leads to lower concentrations of alkali in the pore water. The greater the amount of water, the more movement of the water that will take place. Greater movement allows greater amounts of calcium to be transported by the fluid, leading to a calcium-alkali-silica complex which is nonexpansive.

Calcium and lime are unusual in that their solubilities increase as the temperature decreases. At the lower elevations of the dam, the temperature is lower and, therefore, the solubility of calcium is higher. Thus, the pore water will contain more calcium. Elevated levels of calcium lead to a higher production of nonexpansive calcium-alkali-silica complex.

The unusual strength trend of the concrete on top of the spillways can be explained in similar fashion. While the spillway was in use, the concrete was kept continually wet, thus providing an abundant supply of water for movement into pores, leading to low concentrations of alkali and less expansion. However, the reaction was not completely stopped, as evidenced by the drop in elasticity during this period. The water moving over the spillway kept this concrete at a lower temperature, leading to a higher concentration of calcium in the pore water and slowing or reducing any expansive reactions. When the concrete was allowed to dry and warm, the expansive reactions intensified. This concrete then acted much like the concrete on top of the dam.

The exact reason for the loss in elasticity throughout the dam is hard to explain. The reaction's expansive forces may have caused internal shear failures in the concrete even though these failures deep within the dam have not been severe enough to cause large reductions in compressive strength. The erratic Poisson's ratio values may be due to these shear failures. The weakest plane of the concrete will fail first, so the shear failure could be in any direction since osmotic pressure acts equally in all directions. The Poisson's ratio test results would be unusually high or low, depending upon the direction of these internal shear planes. These internal shear planes will not significantly change the compressive strength until the internal strains or movements become large.

There does not appear to be a stress buildup in the dam. Once internal failure takes place, it is believed that the stress is released. This conclusion is based on the fact that no such stress increases were found when overcoring tests were done in another dam which has also experienced alkali-aggregate reaction [18].

The potential for further reduction in elastic modulus and compressive strength is minimal since we can assume that after 42 years most of the reactive silica and alkali have been consumed. A comparison to the hydration of portland cement can be made. Portland cement continues to hydrate for long periods of time, producing increases in

compressive strength. However, at later ages such as 42 years, the amount of potential hydration that remains is small. The alkalies in the cement are tied up in the cement compounds. These alkalies are released as the cement hydrates. Consequently, most of the alkalies have been released, and it can be assumed that they have entered into a reaction in the 42-year life of Parker Dam.

Small percentages of alkalies and reactive silica could remain to react either expansively or non-expansively. The remaining reaction could be made more expansive by drying out the concrete in the lower portion of the dam. The alkali concentration in the pore water would increase with a corresponding decrease in the calcium solubility. Although higher temperatures and drying may increase the amount of expansive reaction, it is not likely that enough reactive silica and alkalies remain to cause much internal failure. A possible test to confirm this would be to measure the expansion of cores from deep in the dam at relative humidities less than 100 percent and at temperatures like those of ambient conditions at Parker Dam.

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Note: From November 1979 to May 1981, the Bureau of Reclamation was known as the Water and Power Resources Service; consider the names synonymous in this Bibliography.

Table 1. — *Physical properties testing.*

Drill Hole No.	Elevation m	Elevation ft	Compressive Strength MPa	Compressive Strength lb/in²	Density kg/m³	Density lb/ft³	Elastic Properties: Test Stress MPa	Test Stress lb/in²	Poisson's Ratio Tang	Poisson's Ratio Chord	Stress Range MPa	Stress Range lb/in²	Tangential Modulus GPa	Tangential Modulus lb/in² X 10⁶	Stress Range MPa	Stress Range lb/in²	Chord Modulus GPa	Chord Modulus lb/in² X 10⁶
1	137.2	450.0	32.6	4730	2444	152.6	0.3	50		0.123								
							0.7	100		0.120	0.3-0.7	50- 100	8.1	1.18				
							1.4	200		0.098	0.7-1.4	100- 200	9.6	1.39	0.7-1.4	100- 200	9.6	1.39
							2.8	400		0.092	1.4-2.8	200- 400	12.4	1.80	0.7-2.8	100- 400	11.3	1.64
							4.1	600		0.103	2.8-4.1	400- 600	12.3	1.79	0.7-4.1	100- 600	11.7	1.70
1	134.9	442.7	24.9	3610	2436	155.2	0.7	100		0.027	0.3-0.7	50- 100	4.4	0.65				
							1.4	200		0.023	0.7-1.4	100- 200	6.2	0.90	0.7-1.4	100- 200	6.2	0.90
							2.8	400		0.027	1.4-2.8	200- 400	8.2	1.19	0.7-2.8	100- 400	7.4	1.07
1	127.2	417.2	36.0	5215	2432	151.8	0.3	50		0.204								
							0.7	100		0.124	0.3-0.7	50- 100	11.7	1.70				
							1.4	200		0.089	0.7-1.4	100- 200	13.7	1.98	0.7-1.4	100- 200	13.7	1.98
							2.8	400		0.096	1.4-2.8	200- 400	15.3	2.22	0.7-2.8	100- 400	14.7	2.13
							4.1	600		0.100	2.8-4.1	400- 600	15.9	2.30	0.7-4.1	100- 600	15.2	2.20
							5.5	800		0.121	4.1-5.5	600- 800	16.8	2.44	0.7-5.5	100- 800	15.6	2.26
1	125.0	410.0	33.1	4795	2520	157.3	0.3	50		0.013								
							0.7	100		0.124	0.3-0.7	50- 100	13.8	2.00				
							1.4	200		0.185	0.7-1.4	100- 200	13.8	2.00	0.7-1.4	100- 200	13.8	2.00
							2.8	400		0.119	1.4-2.8	200- 400	16.1	2.33	0.7-2.8	100- 400	15.2	2.21
							4.1	600		0.154	2.8-4.1	400- 600	18.0	2.61	0.7-4.1	100- 600	16.2	2.35
							5.5	800		0.154	4.1-5.5	600- 800	18.1	2.63	0.7-5.5	100- 800	16.8	2.43
1	116.8	383.2	27.2	3940	2465	153.9	0.3	50		0.240								
							0.7	100		0.557	0.3-0.7	50- 100	13.8	2.00				
							1.4	200		0.442	0.7-1.4	100- 200	12.2	1.77	0.7-1.4	100- 200	12.2	1.77
							2.8	400		0.363	1.4-2.8	200- 400	14.5	2.11	0.7-2.8	100- 400	13.7	1.98
							4.1	600		0.333	2.8-4.1	400- 600	17.9	2.60	0.7-4.1	100- 600	15.1	2.19
							5.5	800		0.333	4.1-5.5	600- 800	20.6	2.99	0.7-5.5	100- 800	16.3	2.37
1	115.7	379.5	23.8	3445	2444	152.6	0.3	50		0.068								
							0.7	100		0.082	0.3-0.7	50- 100	7.2	1.05				
							1.4	200		0.099	0.7-1.4	100- 200	9.0	1.30	0.7-1.4	100- 200	9.0	1.30
							2.8	400		0.125	1.4-2.8	200- 400	10.8	1.56	0.7-2.8	100- 400	10.1	1.46
1	110.3	361.8	50.7	7360	2478	154.7	0.3	50		0.189								
							0.7	100		0.142	0.3-0.7	50- 100	18.4	2.67				
							1.4	200		0.174	0.7-1.4	100- 200	15.7	2.27	0.7-1.4	100- 200	15.7	2.27
							2.8	400		0.161	1.4-2.8	200- 400	14.7	2.13	0.7-2.8	100- 400	15.0	2.17
							4.1	600		0.164	2.8-4.1	400- 600	20.3	2.95	0.7-4.1	100- 600	16.8	2.43
							5.5	800		0.172	4.1-5.5	600- 800	21.9	3.18	0.7-5.5	100- 800	17.9	2.60
							6.9	1000		0.192	5.5-6.9	800-1000	23.4	3.40	0.7-6.9	100-1000	19.0	2.75

Table 1. — *Physical properties testing.* — Continued

Drill Hole No.	Elevation m	Elevation ft	Compressive Strength MPa	Compressive Strength lb/in²	Density kg/m³	Density lb/ft³	Elastic Properties: Test Stress MPa	Test Stress lb/in²	Poisson's Ratio Tang.	Poisson's Ratio Chord	Stress Range MPa	Stress Range lb/in²	Tangential Modulus GPa	Tangential Modulus lb/in² X 10⁶	Stress Range MPa	Stress Range lb/in2	Chord Modulus GPa	Chord Modulus lb/in² X 10⁶
2	138.2	453.4	23.5	3410	2470	154.2	0.3	50		0.084								
							0.7	100		0.093	0.3-0.7	50- 100	12.3	1.78				
							1.4	200		0.086	0.7-1.4	100- 200	13.8	2.00	0.7-1.4	100- 200	13.8	2.00
							2.8	400		0.115	1.4-2.8	200- 400	16.2	2.35	0.7-2.8	100- 400	15.3	2.22
							4.1	600		0.120	2.8-4.1	400- 600	17.1	2.48	0.7-4.1	100- 600	16.0	2.32
							5.5	800		0.125	4.1-5.5	600- 800	18.3	2.66	0.7-5.5	100- 800	16.6	2.41
2	137.8	452.1	30.4	4405	2425	151.4	0.3	50		0.168								
							0.7	100		0.118	0.3-0.7	50- 100	10.0	1.45				
							1.4	200		0.146	0.7-1.4	100- 200	9.6	1.39	0.7-1.4	100- 200	9.6	1.39
							2.8	400		0.142	1.4-2.8	200- 400	13.9	2.01	0.7-2.8	100- 400	12.1	1.75
							4.1	600		0.149	2.8-4.1	400- 600	13.8	2.00	0.7-4.1	100- 600	12.7	1.84
2	134.8	442.2	29.9	4330	2478	154.7	0.3	50		0.181								
							0.7	100		0.124	0.3-0.7	50- 100	10.0	1.45				
							1.4	200		0.152	0.7-1.4	100- 200	9.6	1.39	0.7-1.4	100- 200	9.6	1.39
							2.8	400		0.145	1.4-2.8	200- 400	13.8	2.00	0.7-2.8	100- 400	12.1	1.75
							4.1	600		0.149	2.8-4.1	400- 600	13.8	2.00	0.7-4.1	100- 600	12.7	1.84
2	129.5	425.0	37.8	5485	2478	154.7	0.3	50		0.276								
							0.7	100		0.175	0.3.0.7	50- 100	14.7	2.13				
							1.4	200		0.188	0.7-1.4	100- 200	15.1	2.19	0.7-1.4	100- 200	15.1	2.19
							2.8	400		0.161	1.4-2.8	200- 400	17.0	2.46	0.7-2.8	100- 400	16.3	2.36
							4.1	600		0.170	2.8-4.1	400- 600	18.3	2.66	0.7-4.1	100- 600	17.0	2.47
							5.5	800		0.180	4.1-5.5	600- 800	20.7	3.00	0.7-5.5	100- 800	17.9	2.60
2	129.1	423.7	27.0	3910	2470	154.2	0.3	50		0.086								
							0.7	100		0.106	0.3-0.7	50- 100	11.7	1.70				
							1.4	200		0.125	0.7-1.4	100- 200	14.1	2.04	0.7-1.4	100- 200	14.1	2.04
							2.8	400		0.118	1.4-2.8	200- 400	14.3	2.08	0.7-2.8	100- 400	14.2	2.06
							4.1	600		0.136	2.8-4.1	400- 600	16.9	2.45	0.7-4.1	100- 600	15.2	2.20
							5.5	800		0.144	4.1-5.5	600- 800	17.6	2.55	0.7-5.5	100- 800	15.8	2.29
2	121.0	403.2	30.9	4480	2498	156.0	0.3	50		0.206								
							0.7	100		0.236	0.3-0.7	50- 100	21.2	3.08				
							1.4	200		0.129	0.7-1.4	100- 200	19.2	2.78	0.7-1.4	100- 200	19.2	2.78
							2.8	400		0.127	1.4-2.8	200- 400	23.2	3.37	0.7-2.8	100- 400	21.7	3.15
							4.1	600		0.149	2.8-4.1	400- 600	25.9	3.76	0.7-4.1	100- 600	23.2	3.37
							5.5	800		0.161	4.1-5.5	600- 800	25.9	3.76	0.7-5.5	100- 800	23.9	3.47
							6.9	1000		0.170	5.5-6.9	800-1000	27.6	4.00	0.7-6.9	100-1000	24.7	3.58

Table 1. — *Physical properties testing.* — Continued

Drill Hole No.	Elevation m	Elevation ft	Compressive Strength MPa	Compressive Strength lb/in²	Density kg/m³	Density lb/ft³	Elastic Properties: Test Stress MPa	Test Stress lb/in²	Poisson's Ratio Tang.	Poisson's Ratio Chord	Stress Range MPa	Stress Range lb/in²	Tangential Modulus GPa	Tangential Modulus lb/in² X 10⁶	Stress Range MPa	Stress Range lb/in²	Chord Modulus GPa	Chord Modulus lb/in² X 10⁶
2	114.5	381.7	30.0	4350	2433	151.9	0.3	50		0.283								
							0.7	100		0.198	0.3-0.7	50- 100	17.2	2.50				
							1.4	200		0.117	0.7-1.4	100- 200	16.6	2.41	0.7-1.4	100- 200	16.6	2.41
							2.8	400		0.112	1.4-2.8	200- 400	20.7	3.00	0.7-2.8	100- 400	19.1	2.77
							4.1	600		0.129	2.8-4.1	400- 600	21.0	3.05	0.7-4.1	100- 600	19.9	2.88
							5.5	800		0.127	4.1-5.5	600- 800	22.1	3.20	0.7-5.5	100- 800	20.4	2.96
							6.9	1000		0.144	5.5-6.9	800-1000	21.9	3.28	0.7-6.9	100-1000	20.8	3.01
2	110.9	364.0	33.5	4860	2465	153.9	0.3	50		0.064								
							0.7	100		0.053	0.3-0.7	50- 100	8.5	1.24				
							1.4	200		0.060	0.7-1.4	100- 200	11.2	1.62	0.7-1.4	100- 200	11.2	1.62
							2.8	400		0.062	1.4-2.8	200- 400	13.3	1.93	0.7-2.8	100- 400	12.5	1.81
							4.1	600		0.102	2.8-4.1	400- 600	17.0	2.46	0.7-4.1	100- 600	14.0	2.03
3	121.6	399.1	27.3	3955	2440	152.3	0.3	50		0.114								
							0.7	100		0.096	0.3-0.7	50- 100	12.1	1.76				
							1.4	200		0.110	0.7-1.4	100- 200	13.0	1.89	0.7-1.4	100- 200	13.0	1.89
							2.8	400		0.119	1.4-2.8	200- 400	15.5	2.25	0.7-2.8	100- 400	14.5	2.11
							4.1	600		0.129	2.8-4.1	400- 600	16.1	2.34	0.7-4.1	100- 600	15.2	2.20
							5.5	800		0.142	4.1-5.5	600- 800	18.1	2.62	0.7-5.5	100- 800	15.9	2.30
3	121.1	397.2	22.1	3210	2425	151.4	0.3	50		0.000								
							0.7	100		0.005	0.3-0.7	50- 100	9.2	1.34				
							1.4	200		0.034	0.7-1.4	100- 200	12.6	1.83	0.7-1.4	100- 200	12.6	1.83
							2.8	400		0.054	1.4-2.8	200- 400	8.7	1.26	0.7-2.8	100- 400	9.7	1.41
							4.1	600		0.079	2.8-4.1	400- 600	12.1	1.75	0.7-4.1	100- 600	10.5	1.53
3	119.3	391.3	30.4	4415	2424	151.3	0.3	50		0.021								
							0.7	100		0.019	0.3-0.7	50- 100	16.2	2.35				
							1.4	200		0.031	0.7-1.4	100- 200	12.1	1.76	0.7-1.4	100- 200	12.1	1.76
							2.8	400		0.045	1.4-2.8	200- 400	12.6	1.83	0.7-2.8	100- 400	12.4	1.80
							4.1	600		0.060	2.8-4.1	400- 600	14.3	2.08	0.7-4.1	100- 600	13.1	1.90
							5.5	800		0.072	4.1-5.5	600- 800	13.6	1.97	0.7-5.5	100- 800	13.2	1.92
3	118.3	388.0	30.5	4430	2428	151.6	0.3	50		0.134								
							0.7	100		0.119	0.3-0.7	50- 100	9.4	1.36				
							1.4	200		0.109	0.7-1.4	100- 200	11.2	1.62	0.7-1.4	100- 200	11.2	1.62
							2.8	400		0.099	1.4-2.8	200- 400	15.0	2.17	0.7-2.8	100- 400	13.4	1.95
							4.1	600		0.107	2.8-4.1	400- 600	16.7	2.42	0.7-4.1	100- 600	14.6	2.12
							5.5	800		0.114	4.1-5.5	600- 800	16.8	2.44	0.7-5.5	100- 800	15.2	2.20

Table 1. — *Physical properties testing.* — Continued

Drill Hole No.	Elevation m	Elevation ft	Compressive Strength MPa	Compressive Strength lb/in²	Density kg/m³	Density lb/ft³	Test Stress MPa	Test Stress lb/in²	Poisson's Ratio	Elastic Properties: Stress Range MPa	Stress Range lb/in²	Tangential Modulus GPa	Tangential Modulus lb/in² X 10⁶	Stress Range MPa	Stress Range lb/in²	Chord Modulus GPa	Chord Modulus lb/in² X 10⁶
3	112.3	364.8	27.5	3990	2449	152.9	0.3	50	0.000								
							0.7	100	0.017	0.3-0.7	50- 100	7.8	1.13				
							1.4	200	0.061	0.7-1.4	100- 200	8.4	1.22	0.7-1.4	100- 200	8.4	1.22
							2.8	400	0.089	1.4-2.8	200- 400	10.1	1.47	0.7-2.8	100- 400	9.5	1.38
							4.1	600	0.101	2.8-4.1	400- 600	15.4	2.24	0.7-4.1	100- 600	11.2	1.63
							5.5	800	0.112	4.1-5.5	600- 800	18.1	2.63	0.7-5.5	100- 800	12.6	1.83
							0.3	50	0.079								
							0.7	100	0.088	0.3-0.7	50- 100	8.3	1.20				
							1.4	200	0.120	0.7-1.4	100- 200	8.6	1.25	0.7-1.4	100- 200	8.6	1.25
							2.8	400	0.118	1.4-2.8	200- 400	11.9	1.73	0.7-2.8	100- 400	10.5	1.53
							4.1	600	0.122	2.8-4.1	400- 600	12.5	1.82	0.7-4.1	100- 600	11.3	1.64
							5.5	800	0.134	4.1-5.5	600- 800	13.2	1.71	0.7-5.5	100- 800	11.8	1.71
3	107.8	353.8	22.1	3210	2459	153.5	0.3	50	0.086								
							0.7	100	0.048	0.3-0.7	50- 100	8.2	1.19				
							1.4	200	0.039	0.7-1.4	100- 200	11.2	1.63	0.7-1.4	100- 200	11.2	1.63
							2.8	400	0.049	1.4-2.8	200- 400	13.2	1.92	0.7-2.8	100- 400	12.5	1.81
							4.1	600	0.070	2.8-4.1	400- 600	17.7	2.57	0.7-4.1	100- 600	14.1	2.05
							5.5	800	0.089	4.1-5.5	600- 800	15.2	2.21	0.7-5.5	100- 800	14.5	2.10
							6.9	1000	0.130	5.5-6.9	800-1000	14.8	2.14	0.7-6.9	100-1000	14.5	2.11
3	106.9	350.7	32.1	4660	2446	152.7	0.3	50	0.131								
							0.7	100	0.104	0.3-0.7	50- 100	12.5	1.82				
							1.4	200	0.100	0.7-1.4	100- 200	13.4	1.94	0.7-1.4	100- 200	13.4	1.94
							2.8	400	0.107	1.4-2.8	200- 400	14.1	2.05	0.7-2.8	100- 400	13.9	2.01
							4.1	600	0.107	2.8-4.1	400- 600	16.7	2.42	0.7-4.1	100- 600	14.9	2.16
							5.5	800	0.109	4.1-5.5	600- 800	18.3	2.66	0.7-5.5	100- 800	15.7	2.28
							6.9	1000	0.112	5.5-6.9	800-1000	19.1	2.77	0.7-6.9	100-1000	16.3	2.37
3	99.8	327.4	31.1	4510	2457	153.4	0.3	50	0.217								
							0.7	100	0.182	0.3-0.7	50- 100	11.9	1.72				
							1.4	200	0.171	0.7-1.4	100- 200	14.1	2.04	0.7-1.4	100- 200	14.1	2.04
							2.8	400	0.172	1.4-2.8	200- 400	18.7	2.71	0.7-2.8	100- 400	16.8	2.44
							4.1	600	0.175	2.8-4.1	400- 600	21.7	3.15	0.7-4.1	100- 600	18.5	2.68
							5.5	800	0.182	4.1-5.5	600- 800	22.8	3.30	0.7-5.5	100- 800	19.6	2.84
3	99.0	324,8	39.9	5780	2443	152.5	0.3	50	0.008								
							0.7	100	0.019	0.3-0.7	50- 100	11.0	1.60				
							1.4	200	0.019	0.7-1.4	100- 200	13.0	1.89	0.7-1.4	100- 200	13.0	1.89
							2.8	400	0.030	1.4-2.8	200- 400	14.8	2.14	0.7-2.8	100- 400	14.1	2.05
							4.1	600	0.046	2.8-4.1	400- 600	23.4	3.39	0.7-4.1	100- 600	16.8	2.44
							5.5	800	0.057	4.1-5.5	600- 800	17.9	2.60	0.7-5.5	100- 800	17.1	2.48
							6.9	1000	0.067	5.5-6.9	800-1000	18.0	2.61	0.7-6.9	100-1000	17.3	2.51

Table 1. — *Physical properties testing.* — Continued

Drill Hole No.	Elevation m	Elevation ft	Compressive Strength MPa	Compressive Strength lb/in²	Density kg/m³	Density lb/ft³	Elastic Properties: Test Stress MPa	Test Stress lb/in²	Poisson's Ratio Tang.	Poisson's Ratio Chord	Stress Range MPa	Stress Range lb/in²	Tangential Modulus GPa	Tangential Modulus lb/in² X 10⁶	Stress Range MPa	Stress Range lb/in²	Chord Modulus GPa	Chord Modulus lb/in² X 10⁶
3	92.6	303.7	35.3	5120	2452	153.1	0.3	50		0.021								
							0.7	100		0.020	0.3-0.7	50- 100	9.8	1.42				
							1.4	200		0.032	0.7-1.4	100- 200	11.9	1.73	0.7-1.4	100- 200	11.9	1.73
							2.8	400		0.065	1.4-2.8	200- 400	14.1	2.04	0.7-2.8	100- 400	13.2	1.92
							4.1	600		0.084	2.8-4.1	400- 600	15.8	2.29	0.7-4.1	100- 600	14.1	2.05
							5.5	800		0.097	4.1-5.5	600- 800	17.8	2.58	0.7-5.5	100- 800	15.0	2.18
3	91.2	299.1	35.0	5080	2449	152.9	0.3	50		0.063								
							0.7	100		0.020	0.3-0.7	50- 100	14.5	2.11				
							1.4	200		0.015	0.7-1.4	100- 200	18.7	2.71	0.7-1.4	100- 200	18.7	2.71
							2.8	400		0.018	1.4-2.8	200- 400	20.9	3.03	0.7-2.8	100- 400	20.1	2.92
							4.1	600		0.026	2.8-4.1	400- 600	17.7	2.56	0.7-4.1	100- 600	19.0	2.76
							5.5	800		0.038	4.1-5.5	600- 800	21.6	3.14	0.7-5.5	100- 800	19.7	2.86
							6.9	1000		0.051	5.5-6.9	800-1000	19.2	2.79	0.7-6.9	100-1000	19.7	2.85
4	120.5	395.2	17.2	2490	2412	150.6	0.3	50	0.059	0.059								
							0.7	100	0.095	0.078	0.3-0.7	50- 100	4.6	0.67				
							1.0	150	0.141	0.096	0.7-1.0	100- 150	6.3	0.91	0.7-1.0	100- 150	6.3	0.91
							1.4	200	0.169	0.110	1.0-1.4	150- 200	7.2	1.04	0.7-1.4	100- 200	6.7	0.97
							1.7	250	0.177	0.120	1.4-1.7	200- 250	8.2	1.19	0.7-1.7	100- 250	7.1	1.03
							2.1	300	0.150	0.124	1.7-2.1	250- 300	8.6	1.25	0.7-2.1	100- 300	7.4	1.08
							2.8	400	0.163	0.131	2.1-2.8	300- 400	9.1	1.32	0.7-2.8	100- 400	7.9	1.15
							3.4	500	0.224	0.149	2.8-3.4	400- 500	7.0	1.02	0.7-3.4	100- 500	7.7	1.11
4	118.4	388.5	25.3	3670	2473	154.4	0.3	50	0.140	0.140								
							0.7	100	0.201	0.166	0.3-0.7	50- 100	10.3	1.50				
							1.0	150	0.179	0.170	0.7-1.0	100- 150	9.2	1.33	0.7-1.0	100- 150	9.2	1.33
							1.4	200	0.162	0.168	1.0-1.4	150- 200	11.2	1.63	0.7-1.4	100- 200	10.1	1.47
							1.7	250	0.148	0.164	1.4-1.7	200- 250	9.0	1.31	0.7-1.7	100- 250	9.7	1.41
							2.1	300	0.377	0.185	1.7-2.1	250- 300	17.5	2.54	0.7-2.1	100- 300	11.0	1.59
							2.8	400	0.177	0.183	2.1-2.8	300- 400	15.0	2.18	0.7-2.8	100- 400	12.1	1.75
							3.4	500	0.263	0.199	2.8-3.4	400- 500	11.4	1.65	0.7-3.4	100- 500	11.9	1.72
4	113.9	373.8	26.1	3790	2460	153.6	0.3	50	0.147	0.147								
							0.7	100	0.051	0.097	0.3-0.7	50- 100	9.9	1.44				
							1.0	150	0.091	0.095	0.7-1.0	100- 150	11.0	1.60	0.7-1.0	100- 150	11.0	1.60
							1.4	200	0.085	0.092	1.0-1.4	150- 200	10.3	1.50	0.7-1.4	100- 200	10.7	1.55
							1.7	250	0.211	0.112	1.4-1.7	200- 250	12.8	1.86	0.7-1.7	100- 250	11.3	1.64
							2.1	300	0.138	0.116	1.7-2.1	250- 300	12.3	1.78	0.7-2.1	100- 300	11.5	1.67
							2.8	400	0.202	0.134	2.1-2.8	300- 400	14.1	2.04	0.7-2.8	100- 400	12.3	1.78
							3.4	500	0.238	0.150	2.8-3.4	400- 500	16.6	2.41	0.7-3.4	100- 500	13.1	1.90
							6.2	900	0.284	0.197	3.4-6.2	500- 900	18.1	2.63	0.7-6.2	100- 900	15.2	2.21

Table 1. — *Physical properties testing.* — Continued

Drill Hole No.	Elevation m	Elevation ft	Compressive Strength MPa	Compressive Strength lb/in²	Density kg/m³	Density lb/ft³	Test Stress MPa	Test Stress lb/in²	Poisson's Ratio Tang.	Poisson's Ratio Chord	Elastic Properties: Stress Range MPa	Stress Range lb/in2	Tangential Modulus GPa	Tangential Modulus lb/in² X 10⁶	Stress Range MPa	Stress Range lb/in²	Chord Modulus GPa	Chord Modulus lb/in² X 10⁶
4	106.1	348.1	26.2	3800	2449	152.9	0.3	50	0.009	0.009								
							0.7	100	0.009	0.009	0.3-0.7	50- 100						
							1.0	150	0.009	0.009	0.7-1.0	100- 150	8.5	1.26	0.7-1.0	100- 150	8.5	1.26
							1.4	200	0.029	0.014	1.0-1.4	150- 200	9.5	1.38	0.7-1.4	100- 200	9.1	1.32
							1.7	250	0.058	0.021	1.4-1.7	200- 250	11.4	1.65	0.7-1.7	100- 250	9.7	1.41
							2.1	300	0.025	0.021	1.7-2.1	250- 300	12.0	1.74	0.7-2.1	100- 300	10.2	1.48
							2.8	400	0.042	0.025	2.1-2.8	300- 400	13.7	1.99	0.7-2.8	100- 400	11.2	1.61
							3.4	500	0.105	0.038	2.8-3.4	400- 500	13.7	1.98	0.7-3.4	100- 500	11.7	1.70
4	99.4	326.1	36.1	5230	2467	154.0	0.3	50	0.011	0.011								
							0.7	100	0.038	0.025	0.3-0.7	50- 100	9.2	1.33				
							1.0	150	0.066	0.037	0.7-1.0	100- 150	12.8	1.86	0.7-1.0	100- 150	12.8	1.86
							1.4	200	0.181	0.072	1.0-1.4	150- 200	11.0	1.60	0.7-1.4	100- 200	11.9	1.72
							1.7	250	0.205	0.095	1.4-1.7	200- 250	13.3	1.93	0.7-1.7	100- 250	12.3	1.78
							2.1	300	0.215	0.111	1.7-2.1	250- 300	14.0	2.03	0.7-2.1	100- 300	12.7	1.84
							2.8	400	0.151	0.119	2.1-2.8	300- 400	14.7	2.13	0.7-2.8	100- 400	13.3	1.93
							3.4	500	0.230	0.135	2.8-3.4	400- 500	19.5	2.83	0.7-3.4	100- 500	14.4	2.09
4	93.2	305.9	57.3	8310	2446	152.7	0.3	50	0.057	0.057								
							0.7	100	0.044	0.049	0.3-0.7	50- 100	42.4	6.15				
							1.0	150	0.212	0.116	0.7-1.0	100- 150	34.5	5.00	0.7-1.0	100- 150	34.5	5.00
							1.4	200	0.045	0.099	1.0-1.4	150- 200	44.1	5.61	0.7-1.4	100- 200	38.7	5.61
							1.7	250	0.314	0.155	1.4-1.7	200- 250	30.6	4.44	0.7-1.7	100- 250	35.6	5.16
							2.1	300	0.252	0.175	1.7-2.1	250- 300	30.6	4.44	0.7-2.1	100- 300	34.2	4.96
							2.8	400	0.141	0.167	2.1-2.8	300- 400	39.4	5.71	0.7-2.8	100- 400	35.8	5.19
							3.4	500	0.243	0.184	2.8-3.4	400- 500	31.5	4.57	0.7-3.4	100- 500	34.6	5.02
							6.2	900	o.183	0.184	3.4-6.2	500- 900	34.9	5.06	0.7-6.2	100- 900	34.7	5.04
4	90.6	297.3	28.5	4130	2468	154.1	0.3	50	0.037	0.037								
							0.7	100	0.033	0.035	0.3-0.7	50- 100	10.8	1.57				
							1.0	150	0.069	0.046	0.7-1.0	100- 150	11.2	1.63	0.7-1.0	100- 150	11.2	1.63
							1.4	200	0.048	0.047	1.0-1.4	150- 200	11.6	1.68	0.7-1.4	100- 200	11.4	1.66
							1.7	250	0.074	0.051	1.4-1.7	200- 250	14.3	2.08	0.7-1.7	100- 250	12.3	1.78
							2.1	300	0.076	0.055	1.7-2.1	250- 300	14.9	2.16	0.7-2.1	100- 300	12.8	1.86
							2.8	400	0.068	0.058	2.1-2.8	300- 400	14.7	2.13	0.7-2.8	100- 400	13.4	1.94
							3.4	500	0.060	0.058	2.8-3.4	400- 500	16.8	2.44	0.7-3.4	100- 500	14.1	2.05

Table 1. — *Physical properties testing.* — Continued

Drill Hole No.	Elevation m	Elevation ft	Compressive Strength MPa	Compressive Strength lb/in²	Density kg/m³	Density lb/ft³	Elastic Properties: Test Stress MPa	Test Stress lb/in²	Poisson's Ratio Tang.	Poisson's Ratio Chord	Stress Range MPa	Stress Range lb/in²	Tangential Modulus GPa	Tangential Modulus lb/in² X 10⁶	Stress Range MPa	Stress Range lb/in²	Chord Modulus GPa	Chord Modulus lb/in² X 10⁶
4	83.4	273.5	50.3	7300	2464	153.8	0.3	50	0.485	0.485								
							0.7	100	0.402	0.441	0.3-0.7	50- 100	35.6	5.16				
							1.0	150	0.335	0.408	0.7-1.0	100- 150	40.9	5.93	0.7-1.0	100- 150	40.9	5.93
							1.4	200	0.274	0.371	1.0-1.4	150- 200	33.4	4.85	0.7-1.4	100- 200	36.7	5.33
							1.7	250	0.256	0.347	1.4-1.7	200- 250	35.6	5.16	0.7-1.7	100- 250	36.3	5.27
							2.1	300	0.212	0.323	1.7-2.1	250- 300	34.5	5.00	0.7-2.1	100- 300	35.9	5.20
							2.8	400	0.222	0.300	2.1-2.8	300- 400	39.4	5.71	0.7-2.8	100- 400	37.0	5.36
							3.4	500	0.117	0.259	2.8-3.4	400- 500	32.5	4.71	0.7-3.4	100- 500	35.7	5.18
							6.2	900	0.186	0.225	3.4-6.2	500- 900	33.7	4.89	0.7-6.2	100- 900	34.7	5.03
4	76.6	251.3	29.3	4250	2472	154.3	0.3	50	0.098	0.098								
							0.7	100	0.203	0.164	0.3-0.7	50- 100	28.3	4.10				
							1.0	150	0.070	0.116	0.7-1.0	100- 150	17.0	2.46	0.7-1.0	100- 150	17.0	2.46
							1.4	200	0.055	0.096	1.0-1.4	150- 200	17.8	2.58	0.7-1.4	100- 200	17.4	2.52
							1.7	250	0.075	0.091	1.4-1.7	200- 250	18.4	2.67	0.7-1.7	100- 250	17.7	2.57
							2.1	300	0.165	0.103	1.7-2.1	250- 300	23.0	3.33	0.7-2.1	100- 300	18.8	2.72
							2.8	400	0.126	0.108	2.1-2.8	300- 400	24.5	3.56	0.7-2.8	100- 400	20.3	2.95
							3.4	500	0.160	0.118	2.8-3.4	400- 500	25.9	3.76	0.7-3.4	100- 500	21.5	3.12
							6.2	900	0.164	0.137	3.4-6.2	500- 900	25.0	3.63	0.7-6.2	100- 900	23.2	3.36
4	68.5	224.9	51.6	7480	2424	151.3	0.3	50	0.193	0.193								
							0.7	100	0.081	0.132	0.3-0.7	50- 100	19.7	2.86				
							1.0	150	0.168	0.144	0.7-1.0	100- 150	20.4	2.96	0.7-1.0	100- 150	20.4	2.96
							1.4	200	0.103	0.135	1.0-1.4	150- 200	25.1	3.64	0.7-1.4	100- 200	22.5	3.27
							1.7	250	0.123	0.133	1.4-1.7	200- 250	24.0	3.48	0.7-1.7	100- 250	23.0	3.33
							2.1	300	0.101	0.128	1.7-2.1	250- 300	24.5	3.56	0.7-2.1	100- 300	23.4	3.39
							2.8	400	0.140	0.131	2.1-2.8	300- 400	24.8	3.60	0.7-2.8	100- 400	23.8	3.45
							3.4	500	0.168	0.144	2.8-3.4	400- 500	27.2	3.95	0.7-3.4	100- 500	24.6	3.57
							6.2	900	0.142	0.140	3.4-6.2	500- 900	26.6	3.86	0.7-6.2	100- 900	25.5	3.70
4	59.6	195.6	38.1	5530	2438	152.2	0.3	50	0.000	0.000								
							0.7	100	0.017	0.008	0.3-0.7	50- 100	16.2	2.35				
							1.0	150	0.000	0.005	0.7-1.0	100- 150	14.1	2.05	0.7-1.0	100- 150	14.1	2.05
							1.4	200	0.064	0.020	1.0-1.4	150- 200	15.5	2.25	0.7-1.4	100- 200	14.8	2.15
							1.7	250	0.046	0.025	1.4-1.7	200- 250	14.9	2.16	0.7-1.7	100- 250	14.8	2.15
							2.1	300	0.093	0.037	1.7-2.1	250- 300	15.1	2.19	0.7-2.1	100- 300	14.9	2.16
							2.8	400	0.058	0.042	2.1-2.8	300- 400	16.1	2.34	0.7-2.8	100- 400	15.3	2.22
							3.4	500	0.078	0.048	2.8-3.4	400- 500	16.8	2.44	0.7-3.4	100- 500	15.7	2.27
							6.2	900	0.184	0.100	3.4-6.2	500- 900	20.8	3.01	0.7-6.2	100- 900	17.9	2.59

Table 1. — *Physical properties testing.* — Continued

Drill Hole No.	Elevation m	Elevation ft	Compressive Strength MPa	Compressive Strength lb/in²	Density kg/m³	Density lb/ft³	Elastic Properties: Test Stress MPa	Test Stress lb/in²	Poisson's Ratio Tang.	Poisson's Ratio Chord	Stress Range MPa	Stress Range lb/in²	Tangential Modulus GPa	Tangential Modulus lb/in² X 10⁶	Stress Range MPa	Stress Range lb/in²	Chord Modulus GPa	Chord Modulus lb/in² X 10⁶
4	53.2	174.7	30.9	4485	2428	151.6	0.3	50	0.103	0.103								
							0.7	100	0.107	0.105	0.3-0.7	50- 100	13.0	1.88				
							1.0	150	0.207	0.139	0.7-1.0	100- 150	15.5	2.25	0.7-1.0	100- 150	15.5	2.25
							1.4	200	0.229	0.164	1.0-1.4	150- 200	14.0	2.03	0.7-1.4	100- 200	14.7	2.13
							1.7	250	0.279	0.185	1.4-1.7	200- 250	17.0	2.46	0.7-1.7	100- 250	15.4	2.23
							2.1	300	0.199	0.187	1.7-2.1	250- 300	14.9	2.16	0.7-2.1	100- 300	15.2	2.21
							2.8	400	0.251	0.202	2.1-2.8	300- 400	16.8	2.44	0.7-2.8	100- 400	15.8	2.29
							3.4	500	0.323	0.223	2.8-3.4	400- 500	18.5	2.69	0.7-3.4	100- 500	16.3	2.37
							6.2	900	0.319	0.262	3.4-6.2	500- 900	19.4	2.82	0.7-6.2	100- 900	17.8	2.58
4	46.0	151.0	37.4	5430	2468	154.1	0.3	50	0.025	0.025								
							0.7	100	0.155	0.094	0.3-0.7	50- 100	21.6	3.14				
							1.0	150	0.192	0.129	0.7-1.0	100- 150	20.8	3.02	0.7-1.0	100- 150	20.8	3.02
							1.4	200	0.145	0.133	1.0-1.4	150- 200	23.4	3.40	0.7-1.4	100- 200	22.1	3.20
							1.7	250	0.196	0.146	1.4-1.7	200- 250	21.2	3.08	0.7-1.7	100- 250	21.8	3.16
							2.1	300	0.193	0.153	1.7-2.1	250- 300	23.4	3.40	0.7-2.1	100- 300	22.2	3.22
							2.8	400	0.143	0.151	2.1-2.8	300- 400	23.2	3.37	0.7-2.8	100- 400	22.5	3.27
							3.4	500	0.179	0.156	2.8-3.4	400- 500	23.2	3.37	0.7-3.4	100- 500	22.7	3.29
							6.2	900	0.151	0.154	3.4-6.2	500- 900	25.6	3.71	0.7-6.2	100- 900	24.1	3.49

Table 2. — *Compressive strengths by elevation.*

Elevations 137-139 m (450-456 ft)

Core study	Core no.	Elevation m	Elevation ft	Age at test years	Compressive strength* Core diameter 150 mm MPa	Core diameter 6-in lb/in²	Core diameter 250 mm MPa	Core diameter 10-in lb/in²	
1940-41	86	139	456	3	27.4	3980	25.8	3740	
1940-41	86	138	453	3	27.2	3950	25.6	3710	
					27.3	3965			Average
1940-41	7	139	456	4	20.7	3000			
1940-41	11	139	456	4	22.0	3190			
1940-41	13	139	456	4	21.8	3160			
1940-41	27	138	453	4	29.9	4340	28.1	4080	
1940-41	86	137	450	4	29.0	4200	27.2	3950	
					24.7	3580			Average
1943	207	138	453	5	24.4	3540	23.0	3330	
1943	209	137	451	5	38.4	5575	36.1	5240	
					31.4	4560			Average
1945	310	139	456	8	20.9	3030			
1945	311	138	454	8	16.5	2390			
1945	312	138	453	8	20.8	3020			
1945	313	137	451	8	25.2	3650			
					20.9	3025			Average
1949	1-2	139	455	11	19.0	2760			
1949	2-3	138	452	11	24.7	3580			
1949	2-4	137	450	11	20.0	3030			
					21.5	3125			Average
1956	1-A -2	139	455	18	22.1	3210	20.8	3020	
1956	1-A -3	138	452	18	26.5	3850	25.0	3620	
1956	2-A -1	139	456	18	25.3	3670	23.8	3450	
1956	2-A -2	138	454	18	25.7	3725	24.1	3500	
1956	2-A -3	138	452	18	23.7	3435	22.3	3230	
1956	2-A -4	137	450	18	26.3	3820	24.8	3590	
1956	2-A1-1	139	456	18	23.4	3400	22.1	3200	
1956	2-A1-2	138	454	18	21.2	3075	19.9	2890	
					24.3	3525			Average
1980	1	137	450	42	32.6	4730			
1980	2	138	452	42	30.4	4405			
1980	2	138	453	42	23.5	3410			
					28.8	4180			Average

* When 250-mm core data are listed, the adjacent 150-mm core data are a converted equivalent (150-mm core compressive strength = 250-mm core compressive strength ÷ 0.94)

Table 2. — *Compressive strengths by elevation.* — Continued

Core study	Core no.	Elevation m	Elevation ft	Age at test years	Compressive strength* Core diameter 150 mm MPa	Core diameter 6-in lb/in²	Core diameter 250 mm MPa	Core diameter 10-in lb/in²	
Elevations 130-137 m (425-450 ft)									
1940-41	86	137	448	5	34.8	5045	32.7	4740	
1943	210	137	449	5	35.5	5150	33.4	4840	
1945	313	137	449	8	28.8	4180			
1945	315	136	447	8	38.1	5520			
					33.5	4850			Average
1949	1-8	136	447	11	21.9	3170	20.5	2980	
1956	1-A -5	137	448	18	31.0	4500	29.2	4230	
1956	1-A -6	137	446	18	27.1	3935	25.5	3700	
1956	1-A -7	135	443	18	29.3	4245	27.5	3990	
1956	1-A-10	133	437	18	31.2	4530	29.4	4260	
1956	2-A -5	137	448	18	25.5	3700	24.0	3480	
1956	2-A -7	136	446	18	31.5	4565	29.6	4290	
1956	2-A -9	135	442	18	31.6	4585	29.7	4310	
1956	2-A-10	134	440	18	35.2	5105	33.1	4800	
1956	2-A-11	133	437	18	37.5	5445	35.3	5120	
1956	2-A-13	132	433	18	31.3	4545	20.4	4270	
					31.1	4515			Average
1980	1	135	443	42	24.9	3610			
1980	2	130	425	42	37.8	5485			
1980	2	135	442	42	29.9	4330			
					30.9	4475			Average
Elevations 122-130 m (400-425 ft)									
1940-41	46	126	413	3	25.3	3670	23.8	3450	
1940-41	47	126	413	4	34.0	4930			
1940-41	47	126	413	7	28.3	4100			
1980	1	125	410	42	33.1	4795			
1980	1	127	417	42	36.0	5215			
1980	2	123	403	42	30.9	4480			
1980	2	129	424	42	27.0	3910			
					31.8	4600			Average

Table 2. — *Compressive strengths by elevation.* — Continued

Elevations 114-122 m (375-400 ft)

Core study	Core no.	Elevation m	Elevation ft	Age at test years	Compressive strength* Core diameter 150 mm MPa	Core diameter 6-in lb/in²	Core diameter 250 mm MPa	Core diameter 10-in lb/in²	
1938	4	120	393	—	25.3	3670			
1938	7	116	381	—	22.1	3205			
1938	8	119	391	—	22.8	3305			
1938	8A	119	391	—	22.1	3200			
					23.1	3345			Average
1940-41	64	122	400	3	33.2	4820	31.2	4530	
1940-41	64	121	396	3	31.7	4595	29.8	4320	
1940-41	64	119	391	3	36.3	5265	34.1	4950	
1940-41	64	117	383	3	35.6	5160	33.4	4850	
1940-41	64	115	377	3	30.2	4385	28.4	4120	
					33.4	4845			Average
1940-41	51	115	377	4	28.5	4140			
1940-41	64	122	399	4	24.2	3510	22.8	3300	
1940-41	64	118	388	4	33.0	4785	31.0	4500	
					28.6	4145			Average
1940-41	53	115	377	5	32.5	4710			
1940-41	64	116	381	5	36.6	5310	34.4	4990	
1943	200	122	400	5	33.3	4830	31.3	4540	
1943	201	121	398	5	30.4	4405	28.5	4140	
1943	202	121	396	5	34.7	5030	32.6	4730	
					33.5	4855			Average
1940-41	54	115	377	7	22.8	3300			
1940-41	64	120	393	7	34.0	4925	31.9	4630	
1940-41	64	117	385	7	30.8	4465	28.9	4195	
1940-41	64	115	378	7	33.1	4800	31.3	4510	
					30.2	4375			Average
1945	300	122	400	8	34.3	4980			
1945	301	121	398	8	32.2	4670			
1945	302	121	397	8	31.9	4630			
1945	303	121	396	8	29.9	4330			
1945	305	120	394	8	29.0	4200			
1945	306	129	393	8	33.9	4920			
1945	307	119	391	8	31.7	4600			
1945	309	119	389	8	29.9	4340			
					31.6	4585			Average

Table 2. — *Compressive strengths by elevation.* — Continued

Elevations 114-122 m (375-400 ft)

Core study	Core no.	Elevation m	Elevation ft	Age at test years	Compressive strength* Core diameter 150 mm MPa	Core diameter 6-in lb/in²	Core diameter 250 mm MPa	Core diameter 10-in lb/in²	
1956	3-A -1	122	400	18	22.9	3320	21.5	3120	
1956	3-A -2	121	398	18	21.8	3160	20.5	2970	
1956	3-A -3	121	396	18	18.2	2640	17.1	2480	
1956	3-A -4	120	394	18	25.4	3690	23.9	3470	
1956	3-A -5	119	392	18	26.0	3775	24.5	3550	
1956	3-A -6	119	390	18	21.9	3180	20.6	2990	
1956	3-A -7	118	388	18	24.9	3605	23.4	3390	
1956	3-A-10	117	383	18	21.8	3160	20.5	2970	
1956	3-A-11	116	381	18	20.7	3000	19.4	2820	
					22.6	3280			Average
1964	3-1A	122	399	26	24.2	3510			
1964	3-1B	121	398	26	23.4	3400			
1964	3-7A	120	393	26	19.7	2850			
1964	3-10	119	389	26	21.6	3130			
1964	3-11	118	388	26	23.3	3380			
1964	3-15A	117	384	26	27.2	3940			
1964	3-15B	117	383	26	21.6	3130			
1964	3-17A	116	381	26	19.5	2830			
1964	3-17B	116	380	26	23.5	3410			
1964	3-18A	115	378	26	23.4	3400			
1964	3-18B	115	377	26	18.1	2620			
1964	4-2	122	399	26	24.1	3490			
1964	4-4	121	397	26	23.8	3430			
1964	4-8A	120	394	26	21.4	3110			
1964	4-9A	119	392	26	21.9	3180			
1964	4-12	118	387	26	25.2	3650			
1964	4-20A	116	381	26	23.0	3340			
1964	4-20B	116	380	26	19.0	2760			
1964	4-21A	115	378	26	23.8	3450			
1964	4-21B	115	377	26	20.8	3010			
1964	4-22	115	376	26	30.8	4470			
					22.8	3310			Average
1980	1	116	379	42	23.8	3445			
1980	1	117	383	42	27.2	3940			
1980	2	116	382	42	30.0	4350			
1980	3	118	388	42	30.5	4430			
1980	3	119	391	42	30.4	4415			
1980	3	121	397	42	22.1	3210			
1980	3	122	399	42	27.3	3955			
1980	4	119	389	42	25.3	3670			
1980	4	120	395	42	17.2	2490			
					26.0	3765			Average

Table 2. — *Compressive strengths by elevation.* — Continued

Core study	Core no.	Elevation m	Elevation ft	Age at test years	Compressive strength* Core diameter 150 mm MPa	Core diameter 6-in lb/in²	Core diameter 250 mm MPa	Core diameter 10-in lb/in²	
Elevations 91-114 m (300-375 ft)									
1938	1	105	343	—	28.1	4075			
1938	2A	112	368	—	28.9	4195			
1938	3	112	368	—	28.3	4110			
1938	5	107	351	—	29.6	4295			
1938	6	113	371	—	21.0	3040			
					27.2	3945			Average
1940-41	64	113	370	4	36.3	5265	34.1	4950	
1940-41	64	111	364	4	28.0	4065	26.3	3820	
1940-41	64	108	353	4	29.6	4300	27.9	4040	
					31.3	4540			Average
1940-41	64	114	373	5	36.2	5255	34.1	4940	
1940-41	64	112	366	5	39.2	5680	36.8	5340	
1940-41	64	110	362	5	30.1	4360	28.3	4100	
1940-41	64	109	356	5	28.8	4170	27.0	3920	
					33.6	4870			Average
1940-41	64	114	375	6	29.0	4200	27.2	3950	
1940-41	64	112	368	6	43.1	6255	40.5	5880	
1940-41	64	107	351	6	27.0	3915	25.4	3680	
					33.0	4790			Average
1980	1	110	362	42	50.7	7360			
1980	2	111	364	42	33.5	4860			
1980	3	93	304	42	35.3	5115			
1980	3	99	325	42	39.9	5785			
1980	3	100	327	42	31.1	4505			
1980	3	107	351	42	32.1	4660			
1980	3	108	354	42	22.1	3210			
1980	3	114	375	42	27.5	3990			
1980	4	93	306	42	57.3	8310			
1980	4	99	326	42	36.1	5230			
1980	4	106	348	42	26.2	3800			
1980	4	114	374	42	26.1	3790			
					34.8	5050			Average
Elevations 46-91 m (150-300 ft)									
1980	3	91	299	42	35.1	5085			
1980	4	46	151	42	37.4	5430			
1980	4	53	175	42	30.9	4485			
1980	4	60	196	42	38.2	5535			
1980	4	69	225	42	51.6	7485			
1980	4	77	251	42	29.3	4245			
1980	4	84	274	42	50.3	7300			
1980	4	91	297	42	28.5	4130			
					37.7	5460			Average

Table 3. — *Shear and sliding friction tests.*

Drill hole no.	Joint elevation m (note)	Joint elevation ft	Normal stress (N) MPa	Normal stress (N) lb/in²	Shear stress (S) MPa	Shear stress (S) lb/in²	Horizontal displacement mm	Horizontal displacement in	Linear regression: Equation, MPa	Linear regression: Phi (degrees)	Linear regression: Cohesion MPa	Linear regression: Cohesion lb/in²
1	109.8	360.4	0.17	25.0	0.54	77.6	0.838	0.033				
	(disbonded)		0.34	50.0	0.96	138.5	0.737	0.029				
			0.52	75.0	1.09	158.0	0.406	0.016				
			0.69	100.0	1.17	170.0	0.381	0.015				
			1.38	200.0	2.02	292.5	0.457	0.018				
			2.07	300.0	2.75	399.0	0.610	0.024	S=0.46+1.116(N)	48.1	0.46	66.7
1	114.5	375.5	0.34	50.0	0.65	93.9	0.711	0.028				
	(disbonded)		0.34	50.0	0.65	94.0	0.457	0.018				
			0.17	25.0	0.34	48.9	0.483	0.019				
			0.52	75.0	0.96	139.0	0.508	0.020				
			0.69	100.0	1.33	193.0	0.711	0.028				
			1.38	200.0	1.97	285.0	0.457	0.018				
			2.07	300.0	2.76	400.0	0.762	0.030	S=0.26+1.239(N)	51.1	0.26	37.7
1	116.0	380.7	0.52	75.0	1.15	166.5	0.330	0.013				
	(disbonded)		0.17	25.0	0.38	55.7	0.356	0.014				
			0.35	50.0	0.63	91.4	0.406	0.016				
			0.69	100.0	1.08	157.0	0.508	0.020				
			1.38	200.0	1.79	260.0	0.787	0.031				
			2.07	300.0	2.41	349.0	0.762	0.030	S=0.36+1.019(N)	45.5	0.36	52.2
1	117.6	385.8	0.69	100.0	1.03	149.0	0.254	0.010				
	(disbonded)		0.69	100.0	1.03	150.0	0.229	0.009				
			0.17	25.0	0.47	68.1	0.813	0.032				
			0.35	50.0	0.68	98.6	0.483	0.019				
			0.52	75.0	0.80	116.5	0.330	0.013				
			1.38	200.0	1.45	210.0	0.508	0.020				
			2.07	300.0	2.06	299.0	0.584	0.023	S=0.40+0.801(N)	38.7	0.40	58.0
1	120.7	395.9	0.17	25.0	0.37	54.0	0.127	0.005				
	(disbonded)		0.35	50.0	1.18	171.0	0.686	0.027				
			0.52	75.0	1.45	210.0	0.381	0.015				
			0.69	100.0	1.52	221.0	0.432	0.017				
			1.38	200.0	2.41	349.0	0.610	0.024				
			2.07	300.0	2.92	424.0	0.635	0.025				
			0.17	25.0	0.79	115.0	0.711	0.028	S=0.60+1.206(N)	50.3	0.60	87.0
1	123.7	405.9	2.07	300.0	3.79	550.0	0.991	0.039				
	(disbonded)		2.07	300.0	3.52	510.0	0.660	0.026				
			0.17	25.0	0.42	60.6	0.381	0.015				
			0.34	50.0	0.34	48.6	1.626	0.064				
			0.52	75.0	0.76	110.0	0.432	0.017				
			0.69	100.0	0.99	143.0	0.483	0.019				
			1.38	200.0	1.63	236.0	0.737	0.029	S=-0.19+1.758(N)	60.4	-0.19	-27.6
1	125.0	410.0	0.17	25.0	0.42	61.0	0.686	0.027				
	(disbonded)		0.17	25.0	0.34	49.3	0.305	0.012				
			0.34	50.0	0.57	82.7	0.305	0.012				
			0.52	75.0	0.82	119.0	0.330	0.013				
			0.69	100.0	0.95	138.0	0.356	0.014				
			1.38	200.0	1.68	244.0	0.457	0.018				
			2.07	300.0	2.17	315.0	0.559	0.022	S=0.26+0.961(N)	43.9	0.26	37.7
1	131.2	430.5	0.34	50.0	1.24	180.0	0.254	0.010				
	(disbonded)		0.17	25.0	0.72	104.0	0.381	0.015				
			0.52	75.0	1.09	158.0	0.152	0.006				
			0.69	100.0	1.30	188.0	0.254	0.010				
			1.38	200.0	2.11	306.0	0.406	0.016				
			2.07	300.0	2.75	399.0	0.457	0.018	S=0.65+1.022(N)	45.6	0.65	94.3

Table 3. — *Shear and sliding friction tests.*— Continued

Drill hole no.	Joint elevation m (note)	Joint elevation ft	Normal stress (N) MPa	Normal stress (N) lb/in²	Shear stress (S) MPa	Shear stress (S) lb/in²	Horizontal displacement mm	Horizontal displacement in	Linear regression: Equation, MPa	Linear regression: Phi (degrees)	Linear regression: Cohesion MPa	Linear regression: Cohesion lb/in²
1	132.5	434.8	0.52	75.0	0.79	114.0	0.102	0.004				
	(disbonded)		0.52	75.0	0.74	107.0	0.178	0.007				
			0.17	25.0	0.29	42.4	0.152	0.006				
			0.34	50.0	0.54	78.2	0.152	0.006				
			0.69	100.0	1.30	188.0	0.203	0.008				
			1.38	200.0	1.99	288.0	0.279	0.011				
			2.07	300.0	2.45	355.0	0.279	0.011	S=0.21+1.161(N)	49.3	0.21	30.5
1	135.7	445.1	0.69	100.0	2.30	333.0	0.787	0.031				
	(disbonded)		0.69	100.0	2.35	341.0	0.686	0.027				
			0.17	25.0	0.48	69.7	0.610	0.024				
			0.34	50.0	0.92	133.0	0.864	0.034				
			0.52	75.0	1.05	152.0	0.813	0.032				
			1.38	200.0	2.36	342.0	0.889	0.035				
			2.07	300.0	2.90	420.0	0.864	0.034	S=0.80+1.156(N)	49.1	0.80	116.0
1	137.2	450.0	1.38	200.0	2.21	321.0	0.991	0.039				
	(disbonded)		1.38	200.0	2.05	297.0	0.660	0.026				
			0.17	25.0	0.31	45.0	0.330	0.013				
			0.34	50.0	0.54	77.9	0.660	0.026				
			0.52	75.0	0.72	104.0	0.483	0.019				
			0.69	100.0	0.90	131.0	0.508	0.020				
			2.07	300.0	2.13	309.0	0.787	0.031	S=0.20+1.133(N)	48.6	0.20	29.0
2	111.2	364.8	2.07	300.0	3.23	467.7	1.422	0.056				
	(disbonded)		0.17	25.0	0.34	48.9	0.279	0.011				
			0.34	50.0	0.54	78.2	0.508	0.020				
			0.52	75.0	0.73	105.9	0.406	0.016				
			0.69	100.0	0.91	132.0	0.483	0.019				
			1.38	200.0	1.62	234.7	0.660	0.026				
			2.07	300.0	2.07	299.9	0.584	0.023	S=0.09+1.212(N)	50.5	0.09	13.1
2	118.9	390.1	0.52	75.0	1.92	278.0	0.508	0.020				
	(intact)		0.52	75.0	0.89	128.5	0.457	0.018				
			0.69	100.0	1.10	159.3	0.559	0.022				
			1.38	200.0	1.82	263.4	0.610	0.024				
			2.07	300.0	2.37	343.1	0.610	0.024				
			0.17	25.0	0.30	43.9	0.178	0.007				
			0.34	50.0	0.43	61.8	0.356	0.014				
			0.52	75.0	0.63	91.1	0.330	0.013	S=0.17+1.115(N)	48.1	1.34	194.4
2	123.0	403.5	0.34	50.0	2.54	368.3	0.686	0.027				
	(intact)		0.34	50.0	0.66	94.5	0.533	0.021				
			0.52	75.0	0.90	130.4	0.508	0.020				
			0.69	100.0	1.11	161.3	0.508	0.020				
			1.38	200.0	1.71	247.7	0.559	0.022				
			2.07	300.0	2.31	335.7	0.737	0.029				
			0.17	25.0	0.45	65.2	0.635	0.025				
			0.34	50.0	0.70	101.0	0.660	0.026	S=0.36+0.962(N)	43.9	2.20	319.5
2	124.7	409.2	1.38	200.0	4.43	643.0	1.194	0.047				
	(intact)		1.38	200.0	3.34	485.0	1.270	0.050				
			2.07	300.0	3.04	441.0	0.762	0.030				
			0.17	25.0	0.42	60.7	0.305	0.012				
			0.34	50.0	0.59	85.0	0.508	0.020				
			0.52	75.0	0.83	121.0	0.559	0.022				
			0.69	100.0	1.03	150.0	0.457	0.018				
			0.69	100.0	1.05	152.0	0.457	0.018	S=0.07+1.670(N)	59.1	2.13	308.2

Table 3. — *Shear and sliding friction tests.* — Continued

Drill hole no.	Joint elevation m (note)	Joint elevation ft	Normal stress (N) MPa	Normal stress (N) lb/in²	Shear stress (S) MPa	Shear stress (S) lb/in²	Horizontal displacement mm	Horizontal displacement in	Linear regression Equation, MPA	Linear regression Phi (degrees)	Linear regression Cohesion MPa	Linear regression Cohesion lb/in²
2	129.5	425.0	1.38	200.0	1.34	195.0	0.432	0.017				
	(disbonded)		1.38	200.0	1.38	200.0	0.406	0.016				
			1.38	200.0	1.84	267.0	0.889	0.035				
			2.07	300.0	2.56	371.0	0.559	0.022				
			0.17	25.0	0.34	48.9	0.178	0.007				
			0.34	50.0	0.48	69.2	0.254	0.010				
			0.52	75.0	0.68	99.3	0.406	0.016				
			0.69	100.0	0.84	122.0	0.381	0.015				
			1.38	200.0	1.46	212.0	0.508	0.020	S=0.08+1.098(N)	47.7	0.08	11.6
2	131.1	430.2	0.17	25.0	0.43	62.1	0.914	0.036				
	(disbonded)		0.34	50.0	0.72	105.0	0.457	0.018				
			0.52	75.0	0.99	144.0	0.406	0.016				
			0.69	100.0	1.29	187.0	0.406	0.016				
			1.38	200.0	2.05	298.0	0.432	0.017				
			2.07	300.0	2.83	411.0	0.533	0.021				
			0.17	25.0	0.28	40.3	0.203	0.008	S=0.24+1.288(N)	52.2	0.24	34.8
2	135.6	445.3	0.52	75.0	1.25	182.0	0.762	0.030				
	(disbonded)		0.69	100.0	1.50	218.0	0.584	0.023				
			1.38	200.0	2.45	356.0	0.559	0.022				
			2.07	300.0	2.99	433.0	0.635	0.025				
			0.17	25.0	0.30	43.3	0.229	0.009				
			0.34	50.0	0.49	70.4	0.381	0.015				
			0.52	75.0	0.72	104.0	0.432	0.017	S=0.20+1.456(N)	55.5	0.20	29.0
2	137.1	449.7	0.35	50.0	1.77	257.0	1.575	0.062				
	(disbonded)		0.52	75.0	1.63	236.0	1.219	0.048				
			0.69	100.0	1.75	254.0	2.540	0.100				
			1.38	200.0	2.79	404.0	2.388	0.094				
			2.07	300.0	3.37	489.0	1.905	0.075				
			0.17	25.0	0.42	60.3	1.270	0.050				
			0.34	50.0	0.68	99.3	1.905	0.075	S=0.66+1.410(N)	54.7	0.66	95.7
3	111.2	364.8	0.17	25.0	2.70	391.6	0.889	0.035				
	(intact)		0.17	25.0	0.34	48.7	0.279	0.110				
			0.34	50.0	0.70	101.0	0.508	0.200				
			0.52	75.0	0.93	135.3	0.635	0.025				
			0.69	100.0	1.11	160.6	0.508	0.020				
			1.38	200.0	1.72	249.0	0.559	0.022				
			2.07	300.0	2.19	317.6	0.635	0.025				
			0.17	25.0	0.27	39.7	0.178	0.007	S=0.29+0.977(N)	44.3	2.53	367.5
3	114.5	375.5	0.69	100.0	1.83	264.8	0.584	0.023				
	(disbonded)		1.38	200.0	2.77	401.7	0.559	0.022				
			2.07	300.0	3.55	515.1	0.635	0.025				
			0.17	25.0	0.38	55.8	0.178	0.007				
			0.34	50.0	0.58	84.7	0.635	0.025				
			0.52	75.0	0.82	118.9	0.406	0.016				
			0.69	100.0	1.07	154.9	0.432	0.017	S=0.10+1.758(N)	60.4	0.10	14.5
3	117.5	385.3	0.69	100.0	3.15	457.1	0.940	0.037				
	(intact)		0.69	100.0	1.18	171.1	1.118	0.044				
			1.38	200.0	2.09	302.6	0.889	0.035				
			2.07	300.0	2.93	425.1	0.813	0.032				
			0.17	25.0	0.50	72.1	0.660	0.026				
			0.34	50.0	0.72	104.5	0.889	0.035				
			0.52	75.0	0.92	133.3	0.432	0.017				
			0.69	100.0	1.25	181.9	0.737	0.029	S=0.29+1.287(N)	52.2	2.26	328.1

Table 3. — *Shear and sliding friction tests.* — Continued

Drill hole no.	Joint elevation m (note)	Joint elevation ft	Normal stress (N) MPa	Normal stress (N) lb/in²	Shear stress (S) MPa	Shear stress (S) lb/in²	Horizontal displacement mm	Horizontal displacement in	Linear regression: Equation, MPa	Linear regression: Phi (degrees)	Linear regression: Cohesion MPa	Linear regression: Cohesion lb/in²
3	120.7	395.9	0.34	50.0	0.83	120.2	1.194	0.047				
	(disbonded)		0.52	75.0	1.03	149.0	0.406	0.016				
			0.69	100.0	1.25	181.3	0.432	0.017				
			1.38	200.0	2.17	314.1	0.584	0.023				
			2.07	300.0	2.81	407.4	0.711	0.028				
			0.17	25.0	0.36	52.1	0.203	0.008				
			0.34	50.0	0.59	86.2	0.356	0.014	S=0.28+1.276(N)	51.9	0.28	40.6
4	106.8	350.5	0.52	75.0	2.99	433.2	0.813	0.032				
	(intact)		0.52	75.0	1.06	153.4	0.432	0.017				
			0.69	100.0	1.22	176.9	0.432	0.017				
			1.38	200.0	2.15	312.3	0.686	0.027				
			2.07	300.0	2.81	407.9	0.508	0.020				
			0.17	25.0	0.46	66.8	0.356	0.014				
			0.34	50.0	0.61	88.5	0.508	0.020				
			0.52	75.0	0.82	119.0	0.381	0.015	S=0.27+1.274(N)	51.9	2.33	337.6
4	111.4	365.5	1.38	200.0	2.67	387.4	0.889	0.035				
	(disbonded)		2.07	300.0	2.66	385.6	0.457	0.018				
			0.17	25.0	0.34	48.9	0.178	0.007				
			0.34	50.0	0.45	65.2	0.305	0.012				
			0.52	75.0	0.62	90.5	0.305	0.012				
			0.69	100.0	0.77	112.2	0.305	0.012				
			1.38	200.0	1.36	197.3	0.406	0.016	S=0.01+1.345(N)	53.4	0.01	1.5
4	114.6	375.9	0.52	75.0	1.28	185.0	1.143	0.045				
	(disbonded)		0.69	100.0	1.64	237.6	0.610	0.024				
			1.38	200.0	2.44	353.6	0.610	0.024				
			2.07	300.0	3.08	446.1	0.635	0.025				
			0.17	25.0	0.26	38.1	0.203	0.008				
			0.34	50.0	0.44	63.5	0.533	0.021				
			0.52	75.0	0.69	99.8	0.330	0.013	S=0.18+1.507(N)	56.4	0.18	26.1
4	117.7	386.2	1.38	200.0	3.33	482.5	0.711	0.028				
	(intact)		1.38	200.0	2.23	324.1	0.432	0.017				
			2.07	300.0	2.86	414.1	0.533	0.021				
			0.17	25.0	0.37	53.1	0.203	0.008				
			0.34	50.0	0.47	67.5	0.254	0.010				
			0.52	75.0	0.71	102.6	0.330	0.013				
			0.69	100.0	0.89	128.7	0.305	0.012				
			1.38	200.0	1.63	235.9	0.584	0.023	S=0.03+1.362(N)	53.7	1.45	210.3
4	120.7	395.9	0.17	25.0	0.58	78.0	0.889	0.035				
			0.34	50.0	0.95	137.8	0.508	0.020				
			0.52	75.0	1.17	170.4	0.381	0.015				
			0.69	100.0	1.42	205.8	0.381	0.015				
			1.38	200.0	2.02	293.7	0.483	0.019				
			2.07	300.0	2.79	404.3	0.584	0.023				
			0.17	25.0	0.35	50.8	0.203	0.008	S=0.43+1.172(N)	49.5	0.43	62.4
Breakbond-intact joints												
2	118.9	390.1	0.52	75.0	1.92	278.0	0.508	0.020				
2	123.1	403.5	0.35	50.0	2.54	368.3	0.686	0.027				
2	124.7	409.2	1.38	200.0	4.43	643.0	1.194	0.047				
3	111.2	364.8	0.17	25.0	2.70	391.6	0.889	0.035				
3	117.4	385.3	0.69	100.0	3.15	457.1	0.940	0.037				
4	106.8	350.5	0.52	75.0	2.99	433.2	0.813	0.032				
4	117.7	386.2	1.38	200.0	3.33	482.5	0.711	0.028	S=2.13+1.229(N)	50.9	2.13	308.8
									S=0.29+1.230(N)	50.9	0.29	41.5
Overall average, nonbonded sliding friction												

Table 4. — *Condition of construction joints.*

Elevation group		Total joints crossed	Number	Percentage
m	ft	for this elevation	intact	intact
122-137	400-450	22	4	18
107-122	350-400	36	8	22
91-107	300-350	20	5	25
76- 91	250-300	15	7	47
61- 76	200-250	10	3	30
46- 61	150-200	10	6	60

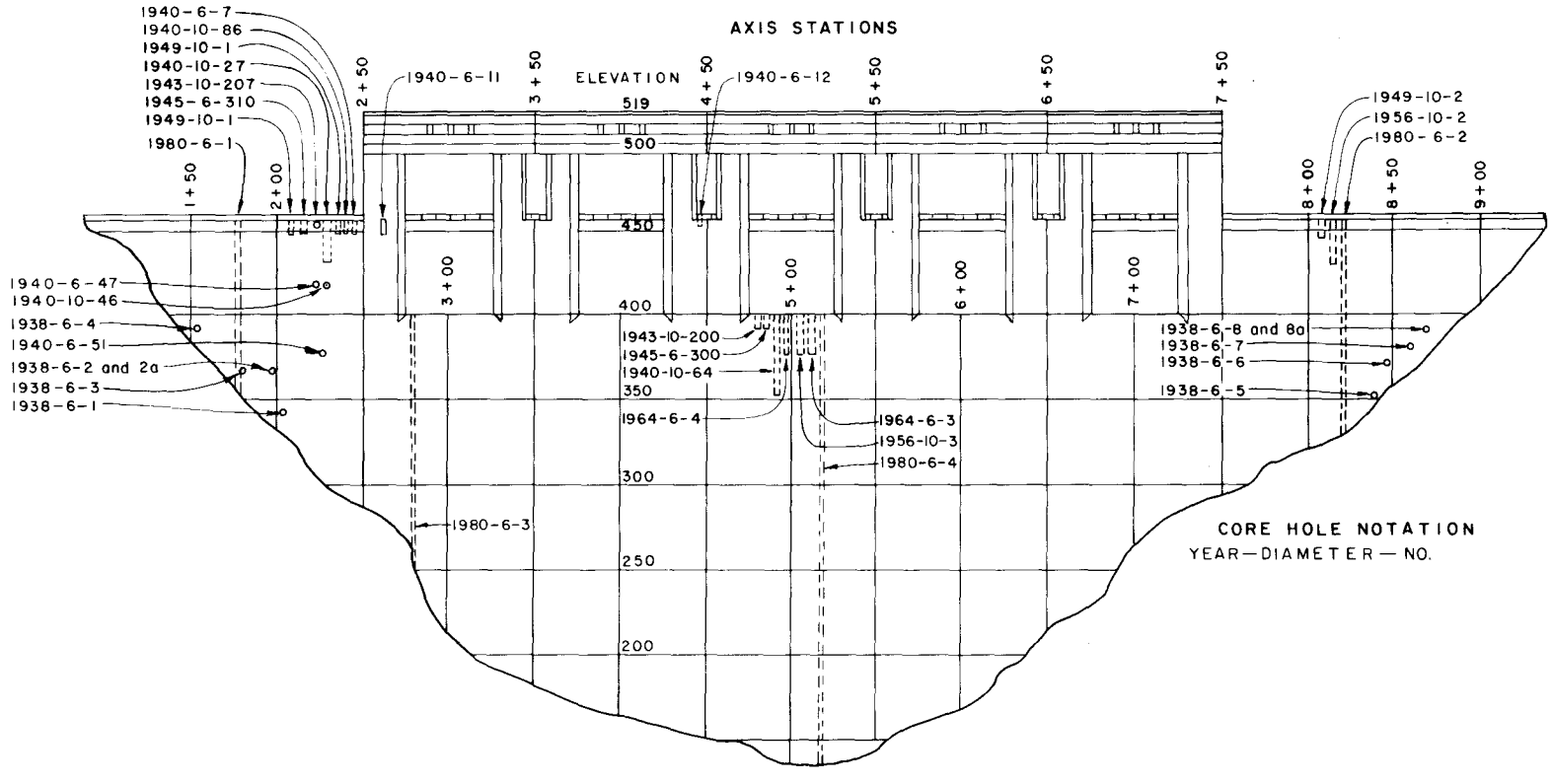

Figure 1.—Core locations, Parker Dam.

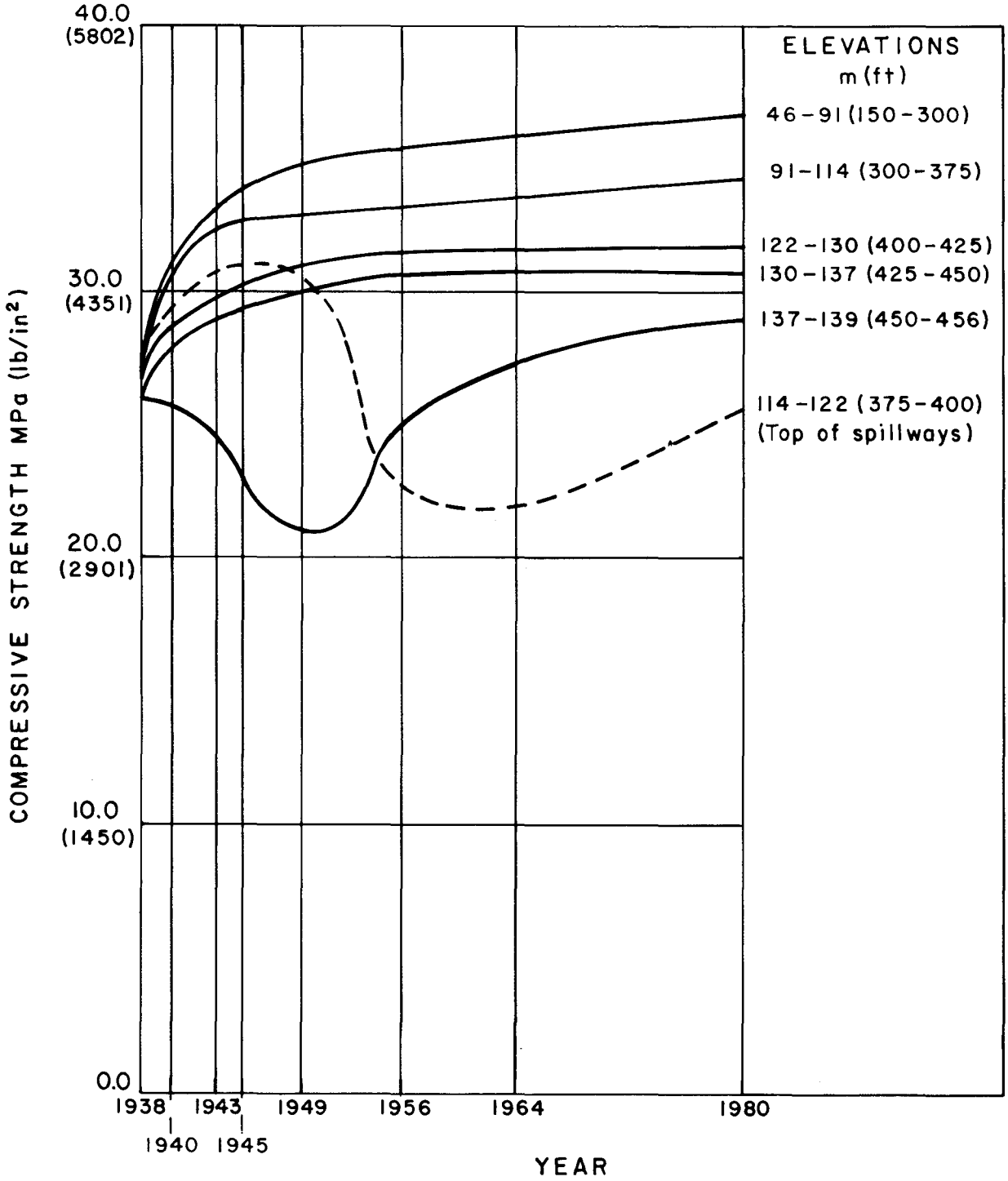

Figure 2.—Compressive strength versus age and elevation, Parker Dam.

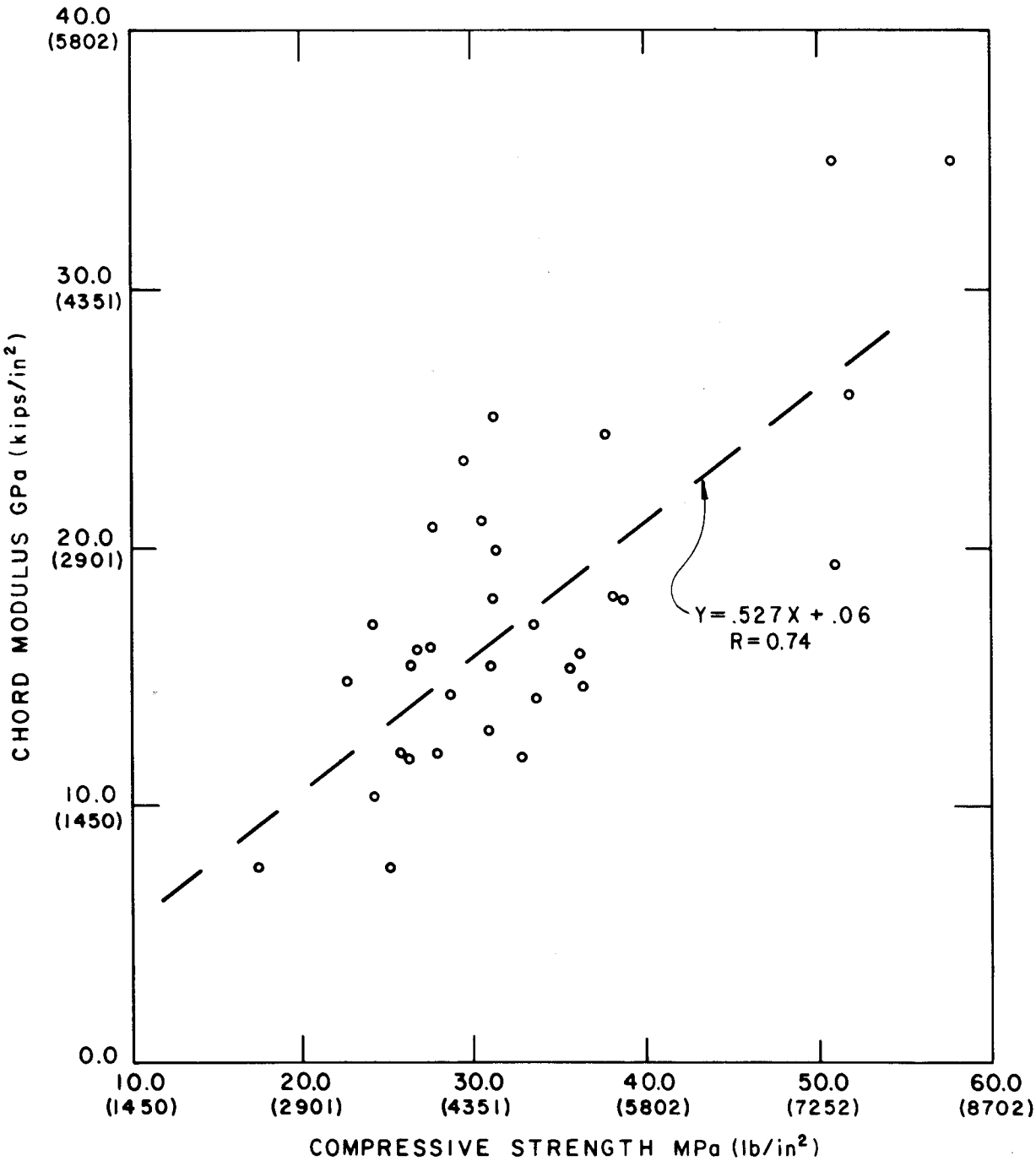

Figure 3.—Compressive strength versus chord modulus of elasticity, Parker Dam, 1980 cores.

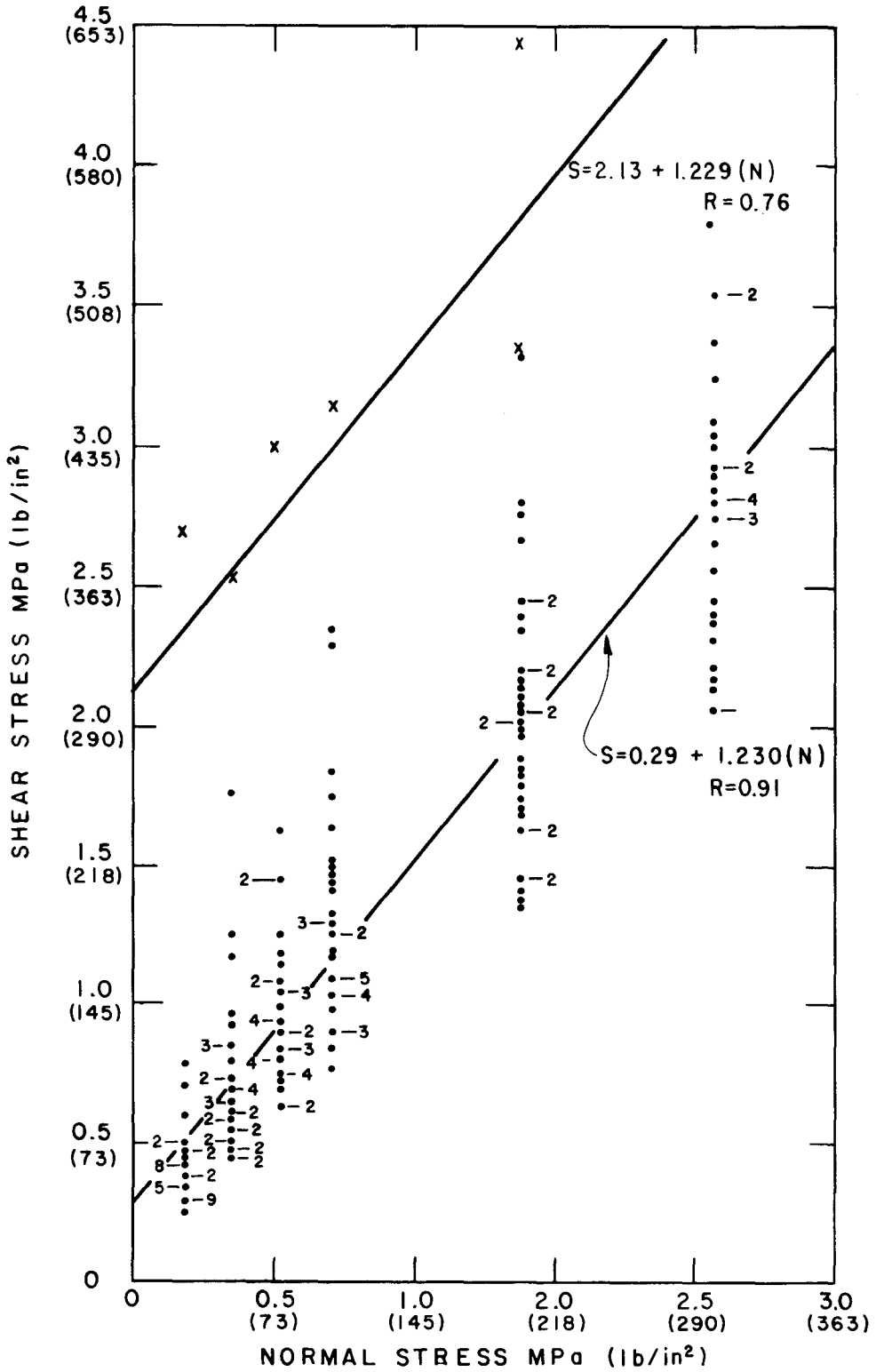

Figure 4. — Normal stress versus shear stress, Parker Dam.

APPENDIX

OPTIONAL FORM NO. 10
JULY 1973 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

Memorandum

TO : Chief, Concrete and Structural Branch JRG 12/12

Denver, Colorado
DATE: December 8, 1981

FROM : Chief, Applied Sciences Branch

SUBJECT: Petrographic Examination of Concrete Core - Parker Dam - Parker-Davis Project, Arizona

Examined by: G. J. Sheldon

Petrographic referral code: 81-84

INTRODUCTION

A cursory examination of Parker Dam 6-inch-diameter concrete core from vertical drill holes 1, 2, and 4, located on the left abutment, right abutment, and spillway crest (center of dam), respectively, was performed in the Concrete Laboratory to select representative fragments for further examination and testing in the Petrographic Laboratory. A thorough petrographic examination was requested to determine the extent of alkali-aggregate reaction in upper and lower concrete from drill holes 1 and 2 and in concrete at 50-foot intervals in drill hole 4. A comparison of high and low strength concrete from drill holes 1, 2, and 4 was also requested. Concrete from drill hole 3 was tested by the Concrete and Structural Branch, but a petrographic examination was not requested on these specimens.

PETROGRAPHIC EXAMINATION AND DISCUSSION

The selected cores were examined megascopically, microscopically, by X-ray diffraction and differential thermal analyses, and by some qualitative physical and chemical tests.

Attachments 1, 2, and 3 are petrographic descriptions of concrete exhibiting low, moderate, and high relative degrees of alkali-aggregate reaction, respectively, and are summarized as follows:

Low - Reaction rims around only a few glassy volcanic particles; very few absorptive rhyolite particles; strong paste-aggregate bond; no gel-soaked paste; air voids generally unfilled but a very few lined or filled with secondary deposits; very few, generally unfilled fractures in paste.

Moderate - Reaction rims around many glassy volcanic particles; a few absorptive rhyolite particles; moderately strong paste-aggregate bond; a few areas of gel-soaked paste; air voids generally unfilled but a few lined or filled with secondary deposits; a few gel-filled macrofractures in paste and microfractures in both paste and around a few aggregate particles.

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High - Reaction rims around many aggregate particles; numerous absorptive rhyolite particles partially to highly filled and/or replaced with silica gel; weak to moderately strong paste-aggregate bond; numerous areas of gel-soaked paste; most air voids lined or filled with secondary deposits; numerous gel-filled macrofractures and microfractures in paste, both through and around aggregate particles, and separating thick reaction rims from aggregate particles.

Attachment 4, table 1, lists sample locations and compressive strengths for all tested specimens from drill holes 1, 2, and 4 as well as the relative degrees of alkali-aggregate reaction for several specimens determined to be representative of both upper and lower and high and low strength concrete.

Referring to attachment 4, the relative degree of alkali-aggregate reaction in selected concrete from drill hole 1 is generally moderate-high throughout the drill hole with only one specimen classified as high in the upper concrete. The compressive strengths generally do not appear to be greatly influenced by the extent of reaction or the location (elevation) of the specimens in the drill hole, since both the high and low strength specimens have the same degree of reaction and are located throughout the drill hole.

The relative degree of alkali-aggregate reaction in selected concrete from drill hole 2 ranges from high to moderate and generally decreases with greater depth. The compressive strengths, however, are relatively uniform throughout the drill hole and do not appear to be greatly influenced by the location (depth) of the specimens in the drill hole, although the lowest strengths generally correspond to the specimens with the highest degree of reaction.

The relative degree of alkali-aggregate reaction in selected concrete from drill hole 4 ranges from high to low and generally decreases with lower elevation. Although the compressive strengths are somewhat variable, lower strengths and a higher degree of reaction are generally observed in upper concrete and higher strengths and a lower degree of reaction in lower concrete. Therefore, a relationship is apparent between the strengths, relative degrees of reaction, and locations (elevations) of the specimens. This relationship also applies to concrete at 50-foot intervals within the drill hole.

CONCLUSIONS

The concrete in upper portions of Parker Dam appears to be the most highly affected by alkali-aggregate reaction, although the degree of reaction varied between the examined drill holes. The reactions appear to be relatively extensive and uniform throughout drill hole 1, somewhat more extensive in the upper concrete and decreasing in intensity in the lower concrete in drill hole 2, and extensive in the upper concrete but progressively decreasing in intensity in the lower concrete at 50-foot intervals in drill hole 4.

The variability in the degree of alkali-aggregate reaction between drill holes may be related to the location of the drill holes within the dam. Drill holes 1 and 2 are located on the left and right abutments, respectively, and extend from about elevation 450 feet (the top of the dam) to

elevation 350 feet. Drill hole 4, however, is located on a spillway crest near the center of the dam and extends from about elevation 400 feet to elevation 150 feet. The concrete in lower portions of drill hole 4 apparently contained insufficient water for the development of alkali-aggregate reaction and, therefore, exhibits only a low degree of alkali-aggregate reaction. The concrete in drill holes 1 and 2 and the upper portions of drill hole 4, however, apparently contained sufficient water and,therefore, exhibits higher degrees of alkali-aggregate reaction. The degree of reaction in lower portions of drill hole 4 and portions of drill holes 1 and 2 can be expected to intensify in the future if sufficient water becomes available.

The compressive strengths are also variable throughout drill holes 1 and 2, but appear to be related to the location of the specimens within the drill hole and the degree of alkali-aggregate reaction in drill hole 4. Hard silica gel may be acting as a cementing material in some of the numerous filled microfractures, especially in specimens from drill holes 1 and 2 which have a moderate-high degree of reaction and high strengths. These specimens, therefore, should have strengths higher than expected for concrete exhibiting such a high degree of reaction. Compressive strengths in drill hole 4 concrete, although still somewhat variable, progressively increase from upper to lower elevations at 50-foot intervals and appear to be closely related to the degree of reaction.

No evidence of deterioration other than that caused by alkali-aggregate reaction could be detected in the examined concrete. The concrete is only slightly carbonated and appears to be moderately well hydrated. Minor amounts of ettringite and soluble chloride salts are present but do not appear to be causing adverse damage to the concrete at this time. No evidence of freeze-thaw deterioration could be detected.

L. O. Tomblin Jr.

Attachments

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D-915
D-1523

ATTACHMENT 1

Petrographic Examination of Concrete Exhibiting a Low Degree of Alkali-aggregate Reaction - Parker Dam - Parker-Davis Project, Arizona

Cursory observations: 6-inch diameter core; medium gray paste (one sample, DH4-305.9, contained light grayish-white paste); only a few air voids and fractures filled with white secondary deposits; reaction rims around only a few aggregate particles; very few filled fractures.

Petrographic examination:

Aggregate - Gravel: subrounded to angular in shape; consists primarily of granite, gneiss, schist, chert, and glassy volcanics including a very few grayish-pink, highly absorptive, rhyolite particles; a few glassy volcanic particles rimmed and partially filled and/or replaced with generally clear to white silica gel; Sand: angular to subrounded in shape; includes the same rock types found in the gravel as well as monomineralic grains of quartz, feldspar, mica, epidote, and a few miscellaneous detrital minerals; Gravel and Sand: Petrographically of satisfactory physical quality and deleteriously reactive with high-alkali cement in the examined concrete.

Paste - Light gray (white in sample DH 4-305.9 ft); moderately absorptive; slightly reactive with dilute HCl (hydrochloric acid); breaks with hard hammer blows around large aggregate particles and through small gravel- and sand-size particles; strong paste-aggregate bond; generally well distributed with aggregate; no areas soaked with gel.

Air voids - A few small, rounded, entrapped air voids generally unfilled but a very few lined or filled with white secondary depoits.

Secondary products - Minor amounts of white to generally clear, soft to generally hard, silica gel lining or filling only a few air voids and fractures and rimming and partially filling and/or replacing a few glassy volcanic particles; minor calcium aluminum silicate hydrate and vaterite associated with the silica gel; minor amounts of small, white, ettringite crystals and calcium carbonate lining or filling a few air voids; minor amounts of soluble chloride chemically detected.

Hydration products - Minor amounts of calcium silicates and calcium hydroxide (portlandite); numerous unhydrated cement particles; water of hydration appears adequate.

Fractures - A very few macrofractures and microfractures in paste; generally unfilled but a few filled with silica gel.

Reaction rims - Very few present; composed of generally thin to thick, generally hard to soft, and generally clear to white silica gel; around only a few glassy volcanic particles.

Summary of diagnostic features characteristic of a low degree of reaction: reaction rims around only a few glassy volcanic particles; very few absorptive rhyolite particles; strong paste-aggregate bond; no gel-soaked paste; air voids generally unfilled but a very few or lined or filled with secondary deposits; very few, generally unfilled fractures in paste.

ATTACHMENT 2

Petrographic Examination of Concrete Exhibiting a Moderate Degree of Alkali-aggregate Reaction - Parker Dam - Parker-Davis Project, Arizona

Cursory observation: 6-inch-diameter core; brownish-gray paste; a few white secondary deposits lining or filling voids and fractures and coating aggregate particles and paste; reaction rims around a few aggregate particles; a few filled fractures.

Petrographic examination:

Aggregate - Gravel: subrounded to angular in shape; consists primarily of granite, basalt, gneiss, schist, chert, and glassy volcanics including a few grayish-pink, highly absorptive, rhyolite particles; many glassy volcanic particles rimmed and partially filled and/or replaced with generally clear to white silica gel; Sand: angular to subrounded in shape; includes the same rock types found in the gravel as well as monomineralic grains of quartz, feldspar, mica, epidote, and a few miscellaneous detrital minerals; Gravel and Sand: petrographically of fair physical quality and deleteriously reactive with high-alkali cement in the examined concrete.

Paste - Light whitish gray to light gray; highly absorptive; slightly reactive with dilute HCl; breaks with moderately hard hammer blows around large gravel-size aggregate particles and through small gravel- and sand-size particles; moderately strong paste-aggregate bond; generally well distributed with aggregate; a few areas soaked with silica gel.

Air voids - A few small, rounded, entrapped air voids generally unfilled but a few lined or filled with white secondary deposits.

Secondary products - Moderate amounts of white to clear, soft to hard, silica gel lining or filling a few air voids and fractures, rimming and partially filling and/or replacing some glassy volcanic particles, and soaking a few areas of paste; minor calcium aluminum silicate hydrate and vaterite associated with the silica gel; minor amounts of small, white, ettringite crystals and calcium carbonate lining or filling a few air voids; minor amounts of soluble chloride chemically detected.

Hydration products - Minor amounts of calcium silicates and calcuim hydroxide; numerous unhydrated cement particles; water of hydration appears adequate.

Fractures - A few macrofractures and microfractures present; generally filled with silica gel but many unfilled; macrofractures in paste; microfractures both in paste and around a few aggregate particles.

Reaction rims - A few present; composed of generally thin to thick, hard to soft, and generally clear to white silica gel; around many glassy volcanic particles.

Summary of diagnostic features characteristic of a moderate degree of reaction: reaction rims around many glassy volcanic particles; a few absorptive rhyolite particles; moderately strong paste-aggregate bond; a few areas of gel-soaked paste; air voids generally unfilled but a few lined or filled with secondary deposits; a few gel-filled macrofractures in paste and microfractures in both paste and around a few aggregate particles.

ATTACHMENT 3

Petrographic Examination of Concrete Exhibiting a High Degree of Alkali-aggregate Reaction - Parker Dam - Parker-Davis Project, Arizona

Cursory observation: 6-inch-diameter core; brownish-gray paste; numerous white secondary deposits lining or filling voids and fractures and coating aggregate particles and paste; reaction rims around many aggregate particles; numerous filled fractures.

Petrographic examination:

Aggregate - Gravel: subrounded to angular in shape; consists primarily of granite, basalt, gneiss, schist, chert, and glassy volcanics including numerous grayish-pink, highly absorptive, rhyolite particles; many particles rimmed with clear to white silica gel; many absorptive rhyolite particles partially to highly filled and/or replaced with silica gel; a few particles contain gel-filled fractures; Sand: angular to subrounded in shape; includes the same rock types found in the gravel as well as monomineralic grains of quartz, feldspar, mica, epidote, and a few miscellaneous detrital minerals; Gravel and Sand: petrographically of fair physical quality and deleteriously reactive with high-alkali cement in the examined concrete.

Paste - Light whitish gray; highly absorptive; slightly reactive with dilute HCl; breaks with moderate hammer blows around large gravel-size aggregate particles, through small gravel- and sand-size particles, and along gel-filled fractures; weak to moderately strong paste-aggregate bond; generally well distributed with aggregate; numerous areas soaked with silica gel.

Air voids - A few small, rounded, entrapped air voids unfilled to generally lined or filled with white secondary deposits.

Secondary products - Major amounts of white to clear, soft to hard, silica gel lining or filling most air voids and fractures, rimming or partically filling and/or replacing numerous aggregate particles, and soaking large areas of paste; minor calcium aluminum silicate hydrate and vaterite associated with the silica gel; minor amounts of small, white, ettringite crystals and calcium carbonate lining or filling a few air voids; minor amounts of soluble chloride chemically detected.

Hydration products - Minor amounts of calcium silicates and calcium hydroxide; numerous unhydrated cement particles; water of hydration appears adequate.

Fractures - Numerous macrofractures and microfractures; generally filled with silica gel; macrofactures and microfractures in paste, both through and around aggregate particles, and separating thick reaction rims from aggregate particles.

Reaction rims - Many present; composed of thin to thick, hard to generally soft, and clear to white silica gel; around many aggregate particles.

ATTACHMENT 3 - Continued

Summary of diagnostic features characteristic of a high degree of deterioration: reaction rims around many aggregate particles; numerous absorptive rhyolite particles partially to highly filled and/or replaced with silica gel; weak to moderately strong paste-aggregate bond; numerous areas of gel-soaked paste; most air voids lined or filled with secondary deposits; numerous gel-filled macrofractures and microfractures in paste, both through and around aggregate particles, and separating thick reaction rims from aggregate particles.

ATTACHMENT 4

Table 1. - Sample locations, compressive strengths, and relative degrees of alkali-aggregate reaction - Parker Dam - Parker-Davis Project, Arizona

Drill hole	Elevation/ depth 1/ (ft)	Compressive strength 2/ (lb/in^2)	Relative degree of alkali-aggregate reaction 3/
DH-1	449.99	4,730	Moderate-high
	442.71	3,610	High
	417.18	5,220	Moderate-high
	410.02	4,800	4/
	383.15	3,940	4/
	379.48	3,440	Moderate-high
	361.79	7,360	Moderate-high
DH-2	1.6	3,410	High
	2.9	4,410	4/
	12.8	4,330	4/
	30.0	5,480	Moderate-high
	31.3	3,910	High
	51.8	4,480	4/
	73.3	4,350	Moderate
	91.0	4,860	4/
DH-4	*395.2	2,490	High
	388.5	3,670	4/
	373.8	3,790	4/
	*348.1	3,800	High
	326.1	5,230	4/
	305.9	8,310	Low
	*297.3	4,130	Moderate-high
	273.5	7,300	4/
	*251.3	4,250	Moderate
	224.9	7,480	Low
	*195.6	5,530	Low
	174.7	4,490	4/
	*151.0	5,430	Low

1/ Drill holes 1 and 4 are elevations; drill hole 2 is depths.
2/ Test performed by Concrete and Structural Branch.
3/ Refer to attachments 1, 2, and 3 for explanation of low, moderate, and high degrees of alkali-aggregate reaction, respectively.
4/ Specimen not selected for petrographic examination.
* Concrete at 50-foot intervals.

GPO 840-656

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