ALKALI-SILICA REACTIVITY IN FIVE DAMS IN SOUTHWESTERN UNITED STATES

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16. ABSTRACT

Concrete samples from five dams in the Southwest (Coolidge, Friant, Matilija, Parker, and Stewart Mountain Dams) were tested for alkali-silica reactivity. This investigation was intended to study the state of alkali-silica reactivity in the concrete and to determine the potential for additional reactivity.

The four procedures used in this investigation were selected to determine whether the concrete contained potentially reactive silica or enough moisture to cause expansion. These procedures were relative humidity measurements, petrographic examinations, length change measurements, and osmotic cell tests.

Test results showed that the extent of alkali-silica reactivity and the potential for its occurrence varied not only between dams, but also between sample locations within each dam.

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Division of Research and Laboratory Services
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CONTENTS

INTRODUCTION

This report describes an investigation of alkali-silica reactivity in the concrete of five dams in southwestern United States. The following dams were investigated:

Coolidge Dam – near Globe, Arizona
Friant Dam – near Fresno, California
Matilija Dam – near Ventura, California
Parker Dam – near Lake Havasu City, Arizona
Stewart Mountain Dam – near Phoenix, Arizona

Each of these dams had been investigated previously for cracking and other effects caused by reactivity. Numerous reports have been produced since the early 1940's, primarily by the USBR (Bureau of Reclamation) [1,2,3,4].*

The present investigation was directed toward determining the remaining potential for alkali-silica reactivity. The results from this study can be used to determine future rehabilitation or reconstruction needs.

CONCLUSIONS

Based on results of this investigation, the following conclusions have been drawn.

Coolidge Dam

1. Alkali-silica reactivity has caused abnormal expansion and cracking of concrete in upper levels of the dam, where high-alkali cement was reportedly used.

2. Volcanic material of andesitic to rhyolitic composition is the primary reactive component of the aggregate in the concrete.

3. Most of the concrete in the dam appears to contain enough moisture to permit expansion from alkali-silica reactivity. Only concrete within several inches of exposed surfaces is sufficiently dry to preclude expansion.

4. Alkali-silica reactivity appears to have been arrested in the upper levels of the dam because of the depletion of available alkali in the concrete.

5. Alkali-silica reactivity appears not to have developed in the lower levels of the dam because of the lack of available alkali. This probably resulted from the use of lower-alkali cement.

6. Concrete in both the upper and lower portions of the dam contains potentially reactive aggregate.

Friant Dam

1. The extent and severity of alkali-silica reactivity appears to vary considerably with location in the dam. Concrete in the block adjacent to the spillway on the Friant side and concrete in the stairway near the ground-level viewing area had severe cracking caused by reactivity; whereas, concrete at the top of the outlet gatehouse was essentially free from any evidence of previous reactivity.

2. The reactive component of the aggregate was volcanic material of approximately andesitic composition.

3. Most of the concrete in the dam appears to contain enough moisture to permit expansion from alkali-silica reactivity. Only concrete within several inches of exposed surfaces is sufficiently dry to preclude expansion.

4. Concrete taken from the face of the dam and from the roadway atop the dam did not show a potential for expansive reactivity, even in the presence of excess alkali. This suggests the absence of potentially reactive aggregate.

5. Concrete in the stairway near the ground-level viewing area contains aggregate with potential for expansive alkali-silica reactivity.

Matilija Dam

1. Alkali-silica reactivity has caused excessive expansion and severe cracking over widespread areas of the upper portion of the dam, including the arch section and the concrete railings, retaining walls, and stairways.

2. The primary deleteriously reactive component of the aggregate is the shale present in the coarse fraction of the fine aggregate.

3. Nearly all the concrete in the dam structure contains enough moisture to permit expansion from alkali-silica reactivity.

4. Concrete from the dam contains aggregate that is potentially reactive, but only in the presence of added alkali. Lack of significant expansion of concrete in water suggests that expansive reactivity has been arrested because of the depletion of available alkali.

* Numbers in brackets refer to entries in the bibliography.

Parker Dam

1. Expansion and cracking from alkali-silica reactivity have occurred in the upper portions of the dam, at and above the approximate level of the dam roadway, and in the retaining wall along the walkway on the dam. But, there was no evidence of alkali-silica reactivity in concrete cores taken in the powerhouse area.

2. The reactive components of the aggregate are chert and volcanic materials of andesitic to rhyolitic composition.

3. Most of the concrete in the dam structure at about the level of the roadway contains enough moisture to permit expansion from alkali-silica reactivity. Concrete in parts of the dam superstructure and powerhouse wall are, at least periodically, sufficiently dry to preclude expansive reactivity.

4. Concrete in the dam structure and in the retaining wall contains little, if any, potentially reactive aggregate.

5. Concrete in the powerhouse area contains aggregate that can be reactive, but only in the presence of added alkali. The lack of evidence of previous reactivity suggests an absence of sufficient alkali, which will preclude future expansive reactivity.

Stewart Mountain Dam

1. Deleterious alkali-silica reactivity has occurred in the upper and lower levels of the arch structure and in the right thrust block of the dam.

2. The primary reactive components of the aggregate are volcanic materials of andesitic to rhyolitic composition. Certain cherts displayed a minor degree of reactivity.

3. Most of the concrete in the dam contains enough moisture to permit expansion from alkali-silica reactivity. Only concrete within several inches of exposed surfaces is sufficiently dry to preclude expansion.

4. Concrete in the dam still contains potentially reactive aggregate.

5. Deleterious alkali-silica reactivity appears to have been arrested in the dam structure by a depletion of available alkali.

SCOPE OF INVESTIGATION

The scope of this study was to characterize as fully as possible the present state and probable future consequences of alkali-silica reactivity in concrete at each of the five dam sites.

As is well known, the three requirements for expansive alkali-silica reactivity are the availability of sufficient moisture and of sufficient alkali, and the presence of potentially reactive silica. The procedures used in this investigation were primarily selected to determine whether enough moisture was available for reactivity to cause expansion in the concrete, and whether unreacted but potentially reactive silica was present in the aggregate. From these tests, it was considered possible to also determine whether the alkali in the concrete is sufficient to sustain expansive reactivity.

INVESTIGATIVE PROCEDURES

Four test procedures were used to characterize the state of alkali-silica reactivity. These procedures are described below.

Relative Humidity Measurements

RH (relative humidity) measurements were made to determine whether sufficient moisture is available in the concrete to permit expansion from alkali-silica reactivity. Previous work at CTL (Construction Technology Laboratories) had revealed that expansion can develop if the relative humidity of the concrete is greater than 80 to 85 percent, referenced to 70 to 75 °F. These findings were based on comparisons of the changes in length of mortar bars containing high-alkali cement plus reactive aggregate with the changes in length of mortar bars containing the same high-alkali cement and water-cement ratio plus known nonreactive aggregate.

Reactive combinations were stored over water in sealed containers held at 100 °F until expansions reached 0.10 percent. Then these specimens, including nonreactive controls, were transferred to various RH conditions between 35 percent and 100 percent at 40, 73, and 100 °F until constant lengths were measured. Plots of the differences in the change of length against the relative humidity of the reactive and nonreactive cement-aggregate combinations established the minimum RH at which expansion of the reactive combinations exceeded those of the nonreactive combinations. As stated above, the minimum RH above which net expansions developed was 80 to 85 percent RH. It was also found that reactive combinations produced greater shrinkage than nonreactive combinations at RH levels less than 80 to 85 percent. This reflects loss of water and shrinkage of existing alkali-silica gel.

These findings support those of other investigators [5,6] who found that large moisture uptake and expansion of various alkali-silica gels occur at RH levels greater than about 85 percent. Thus, the RH criterion used in this study, above which expansion caused by the uptake of moisture by existing gel reaction products occurs, was 85 percent, referenced to 70 to 75 °F.

Relative humidity measurements were made using a technique developed and previously used in field structures by CTL. This technique consists of drilling powder samples from the concrete using a 1-inch-diameter carbide-tip bit and an electrically driven impact drill. The powder sample thus produced is caught during drilling by a small rubber cup which slips over the drill bit and is pressed against the concrete surface. In this position, the cup also prevents the powder from measurable drying during drilling.

Once collected in the rubber cup, the powder sample is quickly transferred to a 100-cm^3 polypropylene bottle, which is immediately tightly capped to prevent drying. The bottle is then stored at 70 to 75 °F for measurement at that temperature range.

Actual RH measurements are made using a Monfore relative humidity probe developed at the Portland Cement Association [7]. This probe is, in effect, an electrical strain gage, in which a short Dacron thread is attached to one end of a 0.001-inch-diameter Advance wire. When exposed to a particular environment, the Dacron thread lengthens or shortens in response to adsorption of moisture from the environment. This changes the length and, thus, the diameter of the Advance wire and, in turn, results in a change in the electrical resistance of the wire. Through prior calibration and the use of a null indicator, the relative humidity "seen" by the Dacron thread is read directly from a dial on a galvanometer in the electrical measuring circuit. About 10 minutes are required for the probe to reach equilibrium (stable RH reading) with the surrounding environment.

In this investigation, the RH of the powder sample was measured by a probe inserted into the sealed bottle. For this purpose, the original cap on the bottle is quickly replaced by one that contains a tightly fitting 5/32-inch-diameter brass tube, which extends through the cap. Once this cap is in place, the RH probe is immediately inserted through the brass tube and positioned over the powder in the sealed bottle until equilibrium is reached. The indicator on the galvanometer is then adjusted until the null indicator reads "zero." The relative humidity is then read from the galvanometer dial.

Because the procedure involves the transfer of powder from the rubber cup to a plastic bottle and the exchange of caps, the powder sample is exposed to ambient conditions for two short periods, usually no longer than 2 to 3 seconds each. However, various trial procedures have indicated that 20 to 30 seconds of exposure is required to change the RH of the sample 1 percent. In addition, the drilling process has not been found to change the RH of the powder sample. The accuracy of this procedure was determined not to differ more than ± 1 percent from the in-place RH measurements (probe inserted into a tube in undisturbed concrete).

The procedure used in this investigation was adapted to obtain profiles of RH versus depth into the concrete. This was done by procuring powder samples at selected depths of a drill hole. For each sample, a ½-inch depth was drilled, from which the powder was obtained. In most cases RH profiles were developed from samples taken at depths of ½ to 1 inch, 2 to 2½ inches, 4 to 4½ inches, 8 to 8½ inches, 16 to 16½ inches, and 24 to 24½ inches. The ½-inch depth of sample was found to be suitable for this purpose. Powder samples obtained between these depths were discarded. Before drilling for a test sample, the hole was carefully cleaned to avoid contamination.

To determine the potential for expansion from alkali-silica reactivity at a sampled location, the 85 percent threshold RH level was compared with the reading obtained on the powder sample. If the RH of the powder sample was greater than the threshold value, then expansion from reactivity was considered possible.

All samples and RH measurements were taken from June 5 to June 15, 1984.

Petrographic Examination

Several concrete core sections from each dam were examined microscopically to assess the development of alkali-silica reactivity and to identify the reacted components of the aggregate. Each of these core sections was sawed longitudinally, and one sawed surface was finely lapped to better reveal the microstructure of the concrete and manifestations of reactivity. The other half of each core was used to examine freshly fractured surfaces for further evidence of reactivity. The core sections were examined under a stereomicroscope using 7 to 35 magnification. Supplementary observations were made using the petrographic microscope.

Length Change of Concrete Cores

Concrete cores with diameters ranging from 3 to 4 inches were taken at selected locations at each dam site during the summer of 1984. These cores were used to determine the potential for expansion from alkali-silica reactivity. They were also used for petrographic examination.

Testing for length change consisted of immersing certain cores in 1N NaOH solution and immersing "companion" cores in water, both at 100 °F. The companion cores were taken either at side-by-side locations in the dam or from the same core-hole, but not necessarily from exactly the same depth in the dam at those locations.

An effort was made to obtain core sections 10 to 11 inches long. However, because many of the cores were cracked when they were received, they were cut from 6 to 10 inches (in one case 5 inches) long. All core test sections were sawed transversely and fitted at each end with gauge points. Their weights and lengths were measured before immersion in the test solutions. Weights were measured to the nearest gram, and lengths were measured to the nearest 0.0001 inch.

As noted above, companion cores were stored in water or NaOH solution. Immersion in water was used to determine length and weight changes caused by rewetting by partially dried concrete. Equilibrium was identified when the cores reached constant (±1g) weight. This point was taken as a reference on which to assess the potential for expansion from additional alkali-silica reactivity in the companion core immersed in 1N NaOH solution.

Immersion of cores in 1N NaOH solution was intended to "force" any potential expansive alkali-silica reactivity. The difference in expansion between the core in that solution and the companion immersed in water was thought to reflect that potential. Differences in expansion were judged to be significant if they exceeded 0.020 percentage point. Six to eight months was considered sufficient test time to establish meaningful trends.

Several interpretations of results of these tests are possible. After weight equilibrium is reached, significant expansion of cores immersed in water suggests that expansion of concrete in the structure may be due to additional alkali-silica reactivity, or due to uptake of moisture by existing gel reaction products, depending on rates of expansion. Conversely, the lack of significant expansion of cores in water suggests that either alkali or potentially reactive silica, or both, are insufficient to produce additional expansive reactivity.

Expansions of cores immersed in 1N NaOH solution that are significantly greater than those of companion cores immersed in water suggest that unreacted but potentially reactive silica is still present, but that alkali is not sufficient to sustain expansive reactivity. If the expansions of cores in alkali are not significantly greater than the small expansions of their companion cores immersed in water, then potentially reactive silica is no longer present in the concrete.

Osmotic Cell Tests

Osmotic cell tests were run on individual coarse aggregate (reacted and unreacted) particles extracted from concrete cores to determine whether unreacted but potentially alkali-reactive silica was present in those particles. The osmotic cell, in effect, partially simulates a paste-aggregate interface [8]. It is made of Lucite, and consists of a 2-inch-diameter by ¾-inch-deep reaction chamber and a reservoir chamber of the same size separated by a ¼-inch-thick, well-hydrated, cement paste membrane of 0.55 water-cement ratio.

Both chambers are filled with 1N NaOH solution. In addition, the reaction chamber contains 12 g of test aggregate ground to the minus No. 50 plus No. 100 sieve size. A vertically oriented capillary tube is fitted through the top of each chamber, and both tubes are partially filled to the same height with 1N NaOH solution. If expansive reaction occurs between the solution and the aggregate in the reaction chamber, solution flows from the reservoir chamber through the paste membrane and into the reaction chamber. This is known as positive flow and produces a height differential between menisci in the two capillary tubes, which is taken as a measure of the potential for reactivity. Based on field performance, positive flow rates that exceed 2.0 mm per day are considered to reflect potential for deleterious alkali-silica reactivity.

DISCUSSION OF RESULTS

Results of all work carried out in this investigation are presented in appendixes A through E of this report. Discussion of results for individual dams is presented below.

Coolidge Dam

Relative Humidity. – Measurements shown on figures A1 and A2 indicate that atmospheric drying has reduced RH values to below the threshold level for expansive reactivity only within several inches of exposed concrete surfaces. At the five locations sampled, RH values ranged from 25 to 75 percent at the ½ to 1-inch-depth; this is below the 85 percent threshold value. At three of the five sample locations (CA, CC, and CD), RH values exceeded the threshold level at the 2- to 2½-inch-depth, and remained at 98 to 99 percent at greater depth. At location CE, the threshold level was reached at about the 16- to 16½-

inch-depth; this reflects the comparatively greater effect of atmospheric drying on RH values. Location (CE) was in the west face of the right buttress, where the dome protects the concrete from direct exposure to sunlight and rainfall.

Based on RH measurements from a variety of exposure conditions, most of the concrete in Coolidge Dam appears to contain enough moisture to permit expansion if alkali-silica reactivity occurs.

Petrographic Examination of Cores. – Concrete cores from three locations in the dam were examined. Results are shown on figure A3. Core CA, taken from the top of the dam where high-alkali cement was reported to have been used, displayed evidence of deleterious alkali-silica reactivity involving volcanic aggregate particles. In contrast, cores CD and CE, which were taken in a spillway pier and at a lower level of a buttress, did not display evidence of expansive alkali-silica reactivity. Cores CD and CE were taken in concrete reported to contain the lower-alkali cement. If this is true, the use of lower-alkali cement appears to have prevented the development of deleterious reactivity, and the use of high-alkali cement appears to have permitted harmful reactivity to occur.

Length Change of Concrete Cores. – Results of length change measurements of concrete cores immersed in water or in 1N NaOH solution are shown on figures A4 and A5. At location CA, where high-alkali cement was reportedly used, expansion of the cores immersed in water was low, and there were no significant differences between the expansion of cores immersed in water and those in 1N NaOH solution. This lack of potentially reactive aggregate indicates that there is no potential for expansive reactivity in the concrete.

At location CB, where high-alkali cement was also reportedly used, there was no potential for further expansion without additional alkali. This is reflected in the contrast between the 0.380 percent expansion reached by the core immersed in 1N NaOH solution, and the 0.022 percent expansion reached by the core immersed in water. These results imply that unreacted but potentially reactive aggregate exists in the concrete, but that reactivity causing excessive expansion and cracking has been arrested by reduction of the available alkali in the concrete.

Results for concrete from locations CD and CE, presumably where low-alkali cement was used, revealed significant potential for excessive expansion from alkali-silica reactivity. This is indicated by the relatively large expansions of cores immersed in alkali compared with the expansions of cores immersed in water. Because the petrographic examination failed to disclose evidence of significant reactivity, it was concluded that the use of the lower-alkali cement has, thus far, effectively inhibited expansive reactivity in this concrete.

Osmotic Cell Tests. – Two coarse aggregate particles were tested in the osmotic cell. The results are shown on figure A6. Although both particles were andesite porphyries, only the more weathered particle revealed a potential for expansive reactivity. This confirms petrograhpic observations that certain andesites in this aggregate are reactive. It also supports the results of tests on the length changes of cores, which indicated that unreacted but potentially reactive aggregate is present in the concrete. However, because lower-alkali cement, which has been effective in inhibiting reactivity, was apparently used in this concrete, it is unlikely that excessive expansion from alkali-silica reactivity will develop in this concrete in the future.

Friant Dam

Relative Humidity. – The results of RH measurements shown on figures B1 and B2 indicate that atmospheric drying has had only superficial effect in reducing the RH of concrete at the sample locations. At the ½- to 1-inch depth, RH values ranged from 45 to 96 percent, but at the 2- to 2½-inch depth at each location, values reached or exceeded the 85 percent threshold level, and remained well above that level at depths up to at least 24 inches. At four of the five locations sampled, RH values were consistently close to 100 percent. From this it was concluded that similarly high RH levels persist at greater depths from exposed surfaces. It should be noted that measurable rain had fallen two days before sampling, which may have partially accounted for high RH values at the ½- to 1-inch depth at some locations. However, the rainfall is not believed to have influenced measured RH values at depths greater than 4 to 4½ inches.

From these results, it was concluded that most concrete in the dam contains enough moisture to permit expansions to develop if alkali-silica reactivity occurs.

Petrographic Examination of Cores. – Concrete cores from four locations were examined. The results are given on figure B3. At location FA, which was in the face of the dam at the top of the outlet gatehouse, there was no evidence of expansive alkali-silica reactivity. The concrete surface at this location was free of visible cracking. At the three other locations, including the concrete stairway and the roadway at the top of the dam, evidence of varying degrees of reactivity was noted.

Evidence of severe reactivity was noted in core FE, which was taken from the roadway in the concrete block adjacent to the spillway on the Friant side of the dam. This block was cracked and tilted and, at the time of sampling, showed evidence of previous differential movement. The core from the adjacent slab in the roadway displayed only minor evidence of expansive reactivity. Thus, evidence of reactivity in the cores generally reflected the occurrence and the severity of abnormal cracking noted in the field inspection.

Length Changes of Concrete Cores. – Results of length change measurements of concrete cores shown on figures B4 and B5 revealed little or no potential for expansive alkali-silica reactivity. Expansion of core FA-2, which was taken at location FA in the face of the dam and immersed in 1N NaOH solution, exceeded by 0.019 percentage point the expansion reached by the companion core immersed in water. This is approximately the minimum difference considered to represent development of alkali-silica reactivity during the test period.

Cores taken at location FD, also in the face of the dam, showed an expansion difference of only 0.014 percentage point, which is below the significance limit of 0.020 percentage point. In addition, expansion of cores from locations FA and FD, which were immersed in water, reached only 0.004 percent and 0.017 percent, respectively. Collectively, these results indicate that further alkali-silica reactivity is unlikely to develop in these concretes.

Cores taken at location FF in the roadway at the top of the dam showed somewhat different results. Core FF-1, immersed in water, expanded 0.043 percent; whereas, core FF-2, immersed in 1N NaOH solution, expanded 0.021 percent. This suggests rehydration of existing gel in core FF-1, and no potential for further expansive reactivity in core FF-2. Map-cracking was observed at this location in the roadway, and minor evidence of reactivity was noted in the petrographic examination of a core from this location. Results suggest that, although previous reactivity had developed, there is little or no potential for expansive alkali-silica reactivity.

Osmotic Cell Tests. – Two andesite coarse aggregate particles were tested in the osmotic cell. The results are given on figure B6. Andesite particle FA-1, taken from concrete in the face of the dam, was found to be nonreactive. This particle showed no evidence of previous reactivity in the concrete, and the petrographic examination did not reveal evidence of previous reactivity in the concrete core. But, andesite particle FB-1, taken from concrete in the stairway that displayed severe map-cracking, was found to be potentially reactive. It displayed evidence of previous reactivity in the concrete core.

Osmotic cell test results indicate that certain andesite particles are still potentially reactive, although they have previously reacted. It is not known, however, whether sufficient alkali is present in the concrete at this location to sustain reactivity in the future.

Matilija Dam

Relative Humidity. – Results of RH measurements shown on figures C1 and C2 suggest that most concrete in the dam contains enough moisture to permit expansion from alkali-silica reactivity. The data show that atmospheric drying has had little or no effect on reducing relative humidities, even at depths as little as ½ to 1 inch from exposed surfaces. At four of the five locations sampled, RH values exceeded the 85 percent threshold level at this shallow depth. Only at location MA, which was in a massive retaining wall, was the RH less than 85 percent at the ½- to 1-inch depth.

The minimal effects of long-term atmospheric drying at the Matilija Dam site are readily seen in RH measurements at location MB, which was in an 8-inch-thick concrete railing. The concrete, which was exposed to the atmosphere on both vertical surfaces, displayed evidence of reactivity. At the ½- to 1-inch depth from each exposed surface, RH values were 86 percent and 90 percent. At the 2- to 2½-inch and the 4- to 4½-inch depths, RH values were 95 percent. Thus, it is understandable that the higher RH values were found near the surface in the more massive units of the dam structure.

Petrographic Examination of Cores. – Examination of two cores taken from locations on the face of the dam revealed evidence of severe alkali-silica reactivity, as described on figure C3. These locations also displayed severe map-cracking on exposed concrete surfaces. Resulting microcracking and alkali-silica gel deposits were associated with shale particles in the coarser sand sizes.

Length Changes of Concrete Cores. – All concrete cores taken at Matilija Dam were so severely cracked and fragmented that it was impossible to recover sections for length change measurements. Therefore, two core sections taken in 1975 and stockpiled in Ventura were used.

Results shown on figure C4 indicate that potential exists for further reactivity and expansion only when additional alkali is present. This is shown by the 0.479 percent expansion for core M-A2. Core M-A1, which was immersed in water, showed only 0.030 percent expansion. This is in the range expected for dried concrete that has simply been rewet. These results suggest that a deficiency in available alkali, which had the effect of arresting expansive alkali-silica reactivity, developed in this concrete.

Osmotic Cell Tests. – Because of the relatively small size and highly altered condition of reacted aggregate particles, it was not possible to recover sufficient material for osmotic cell tests.

Parker Dam

Relative Humidity. – Results of measurements shown on figures D1 and D2, suggest that RH values are above the 85 percent threshold level for expansive reactivity in most concrete in the dam structure. Only at near-surface depths (generally less than about 2 inches) was concrete sufficiently dry to preclude expansion from reactivity. Similarly high RH levels were found in the 5-foot by 5-foot concrete block at the east end of the wall along the walkway on the dam. Thus, even in certain relatively small concrete members exposed to the atmosphere, RH values were sufficiently high to permit expansion to develop from alkali-silica reactivity.

Two of the five sample locations showed relatively low RH values at depths greater than 4 to 4½ inches. One was above the walkway on the dam in the east column of the west spillway. Here RH values ranged from 10 percent at the ½- to 1-inch depth to 47 percent at the 4- to 4½-inch depth. Reinforcing steel was encountered at the 6-inch depth; thus, no greater depths could be sampled. In this concrete, expansion from reactivity would not develop. However, cracking could develop if the concrete at greater depths contains enough moisture and expansive alkali-silica reactivity occurs.

The other location where comparatively low RH values were found was in the 24-inch-thick north wall of the powerhouse. This wall displayed faint map-cracking, which might represent only shrinkage. However, the border of each crack segment was discolored to dark gray by a colorless transparent deposit in the concrete, which was believed to be alkali-silica gel. The RH value at the ½- to 1-inch depth from the exterior surface was 32 percent, but it increased progressively with depth to 70 percent. This 70 percent RH value was found across the middle third of the wall. It may represent the highest RH level at this location because the room on the interior side of the wall is air-conditioned under intermediate to low (50 percent) relative humidity. Thus, it is believed that alkali-silica reactivity had developed earlier in the wall concrete, causing the observed map-cracking. Gradually, the RH decreased to below the 85 percent threshold level, arresting further expansive reactivity. Accordingly, expansion from reactivity in this wall is not expected to develop in the future.

Petrographic Examination of Cores. – Three concrete cores were examined: one from the dam structure, one from the concrete block at the east end of the wall adjacent to the sidewalk, and one from a core stockpile located at the dam site. The results of the petrographic examinations on these cores are shown on figure D3.

Cores from the dam structure and from the concrete block both revealed evidence of severe alkali-silica reactivity with associated microcracking. Reacted components were found to be volcanic materials of andesitic to rhyolitic composition in both the coarse and the fine aggregate.

Examination of the core from the stockpile failed to reveal evidence of alkali-silica reactivity. This core was reportedly taken from the powerhouse area. Thus, low-alkali cement that effectively controlled reactivity might have been used in this concrete.

Length Change of Concrete Cores. – Four sets of concrete cores were measured for length change after immersion in water or in 1N NaOH solution. Cores in two of the sets were taken from the dam structure, and those in one set were taken from the concrete block at the east end of the retaining wall along the walkway on the dam. Concrete at each of these locations was reportedly made with high-alkali cement. The test results are shown on figures D4 and D5.

Those cores immersed in 1N NaOH solution showed slightly greater expansions than companion cores immersed in water. The maximum difference found was 0.023 percentage point for companion cores PDW-1AA and PDW-1BA. This is approximately the lower limit considered to indicate additional expansive reactivity. However, this difference was established within one to two weeks after testing and remained constant for the duration of the test period. This suggests swelling of existing alkali-silica gel rather than additional expansive reactivity or rewetting of concretes from different moisture conditions. The potential for expansive reactivity no longer exists in this concrete.

The three cores in the other set from the dam structure, all of which were immersed in 1N NaOH solution, produced expansions of 0.029 percent, 0.043 percent (terminated after 2 months), and 0.031 percent. These values were not considered to represent further expansive reactivity because only minor expansions (0.010 percentage point) developed after the initial 7 days immersion.

The two cores from the concrete block at the end of the retaining wall produced results similar to those noted above.

Overall, results of these tests indicate that additional expansive reactivity in these concretes is unlikely to develop because of the lack of potentially reactive aggregate and, possibly, because of the lack of sufficient alkali.

Results for cores from the stockpile, which could contain low-alkali cement, indicate that additional alkali initiated expansive reactivity. This is seen in the 0.066 percent expansion between 7 days and 8 months for the core immersed in 1N NaOH solution, compared with 0.010 percent expansion for the same period for the core immersed in water. The 0.010 percent expansion level also suggests there was no rehydration of existing alkali-silica gel or further expansive reactivity. Comparison of results for these two cores with other results suggest that the concrete was made using lower-alkali cement, and that it has been effective in inhibiting expansive reactivity.

Osmotic Cell Tests. – Because of the highly altered condition and size of coarse aggregate particles, sufficient material could not be recovered for osmotic cell tests.

Stewart Mountain Dam

Relative Humidity. – The results of measurements at six locations in the dam are shown on figures E1 and E2. They indicate that the 85 percent threshold RH value required for development of expansive reactivity was reached at depths ranging from 2 to 16½ inches from exposed surfaces.

The greater depths, which represent greater effects of atmospheric drying, all occurred at vertically exposed surfaces, such as the downstream face of the dam. However, the results also indicate that most, if not all, concrete at depths greater than these contains enough moisture to permit expansions from alkali-silica reactivity. This is indicated by RH values consistently greater than about 95 percent at greater depths.

The slight reductions in RH values at the 4- to 4½-inch depth for locations SF and SG are believed to have been caused by unintentional variations in the sampling and testing procedure. They do not affect the interpretation of results presented above.

Petrographic Examination of Cores. – The results of petrographic examinations on four concrete core sections taken from the dam are shown on figure E3. Alkali-silica reactivity with attendant cracking was noted in each core. It was found to be associated primarily with cryptocrystalline to glassy volcanic aggregate particles of andesitic to rhyolitic composition. Several chert particles also were found to have reacted.

Two of the cores, DH-SE and DH-SF, were taken in the roadway at the top of the dam where map-cracking was noted. Core DH-SG was taken on a vertical surface of the right thrust block, which was free of visible cracking. Thus, the absence of abnormal map-cracking on the exposed surfaces of this structure does not necessarily indicate that deleterious reactivity has not developed in those areas.

Length Change of Concrete Cores. – Concrete cores from five locations were tested, but pairs of cores from only two of these locations were available for direct comparison of expansion after immersion in water or in 1N NaOH solution. The results of these tests are shown on figures E4 and E5. At four of the five locations, the cores developed insignificant expansions after immersion in water or in 1N NaOH solution. Among cores from these locations, the maximum expansion between 7 days (when weight equilibrium was first recorded) and 8 months was only 0.019 percentage point. This developed for core SC-1, which was taken from the roadway at the top of the dam. This expansion is approximately the minimum considered to indicate possible additional reactivity.

The results for cores from the fifth location, SF, are different from those noted above. Here, core SF-1, which was immersed in water, produced 0.065 percent expansion in 7 days and 0.100 percent in 1 month. During the following 7 months, expansion increased only 0.027 percentage point. This level of rapid expansion followed by little additional expansion is believed to be caused by the combined effects of rehydration of existing alkali-silica gel and rewetting of cement paste rather than by further reactivity.

Expansion of companion core SF-2, which was immersed in 1N NaOH solution, reached 0.092 percent at 8 months. In this case, the gradual increase in expansion continued throughout the test period, in contrast to that for core SF-1. The pattern of development and level of expansion for core SF-2 indicate that additional reactivity developed in the presence of additional alkali and involved unreacted but potentially reactive aggregate. Conversely, this result suggests that previous expansive reactivity was arrested because of the depletion of available alkali in the concrete.

Osmotic Cell Tests. – Osmotic cell tests were run on four coarse aggregate particles extracted from two cores, DH-SD and DH-SE. The results of these tests are shown on figure E6. One andesite particle was found to be potentially reactive, while the quartzite, granite, and rhyolite particles were found to be nonreactive. The potential reactivity of the andesite particle supports the conclusion drawn with respect to expansion of core SF-2, which was immersed in 1N NaOH solution.

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APPENDIX A

COOLIDGE DAM

FIGURES

COOLIDGE DAM

Background

Coolidge Dam is located on the Gila River about 20 miles southeast of Globe, Arizona. It is a 249-ft high triple dome dam completed in 1928.

This structure was built prior to recognition of alkali-aggregate reactivity, and alkali contents of the cements actually used are not known. However, from review of "cement plant and quarry operations" of the sources that supplied cement, it was concluded that cement containing about 0.61% alkali as equivalent Na_2O was used at the beginning of construction of the buttresses and domes and most of the spillway retaining walls. It was further concluded that higher-alkali cement, probably about 1.0% as equivalent Na_2O, was used in the upper parts of the superstructure, most of the bridge piers, and the upper parts of the domes and buttresses as well as floors and walls of the east spillay. An exact delineation of where the various cements were used in the structure has not been made.

Concrete aggregate was obtained from a sandbar located about one-half mile down stream from the dam. Petrographic analysis indicated that the coarse aggregate consisted of granite, diorite, gabbro, assorted volcanics, sandstone, limestone and a minor amount of chert. The fine aggregate was reported to contain quartz, feldspar, finer grained rock types presented in the coarse aggregate, volcanic glass, chert, and chalcedony.

Cursory inspection of the dam during this investigation revealed that most of the cracking observed was confined to the upper portions of the dam, including the roadway, parapet walls, and spillway piers. It was also noted that spillway gates had been removed at an earlier date, reportedly because of binding or operational problems. Lower levels of the structure failed to reveal evidence of abnormal cracking or expansion.

SAMPLE	LOCATION	DEPTH IN.	R.H.* %
CA	Sampled vertically over pier, east edge of spillway at western edge of west dome, at end of parapet wall, 5 ft from curb.	1/2 to 1 2 to 2-1/2 4 to 4-1/2 8 to 8-1/2 16 to 16-1/2 24 to 24-1/2	75 97 98 99 98 98
CB	Sampled vertically into roadway east of spillway, 10 ft east of pier, 5 ft from curb, eastbound traffic lane. Hit steel at 8-in. depth.	1/2 to 1 2 to 2-1/2 4 to 4-1/2	45 78 85
CC	Sampled horizontally into wall of east gate of west spillway, beneath roadway, on upper level, 3-1/2 ft up from floor of spillway.	1/2 to 1 2 to 2-1/2 4 to 4-1/2 8 to 8-1/2	25 94 98 99

*Relative humidity referenced to 70 to 75°F.

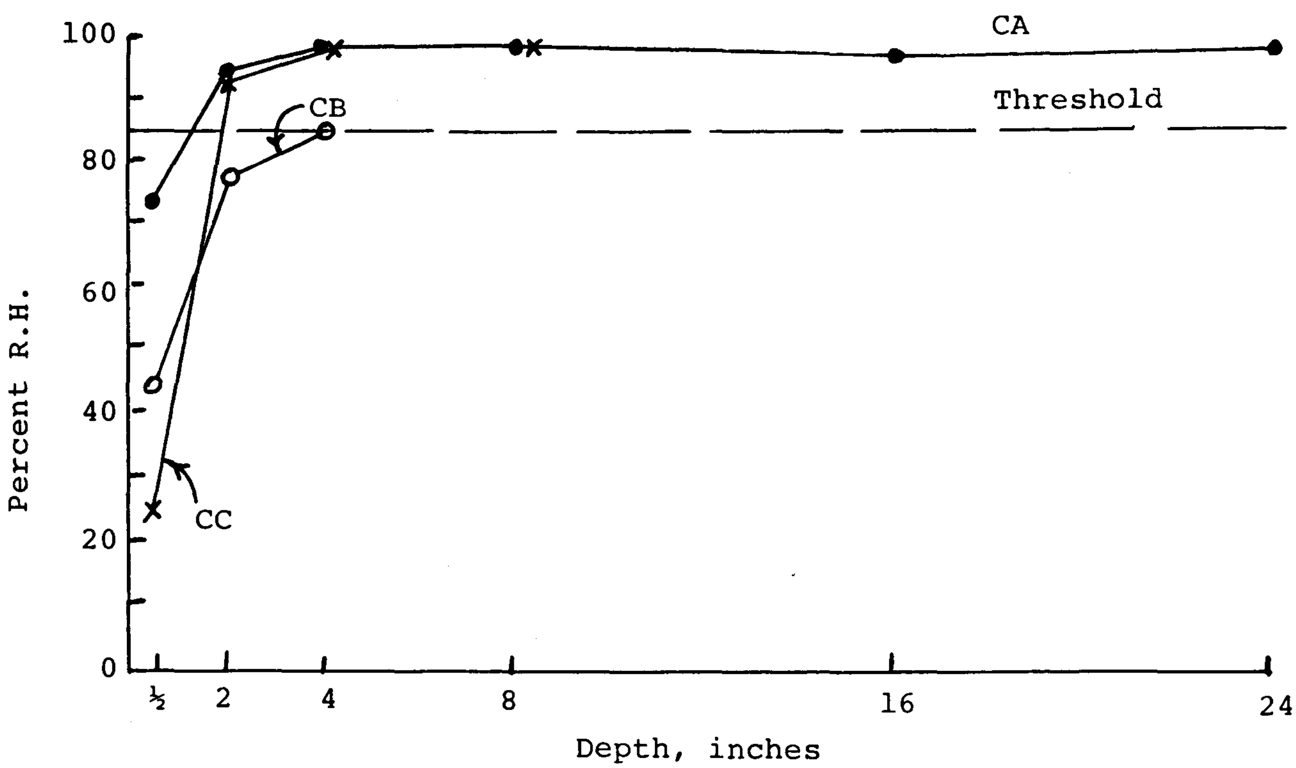

FIG. A1 - RELATIVE HUMIDITY DATA FOR COOLIDGE DAM

SAMPLE	LOCATION	DEPTH IN.	R.H.* %
CD	Sampled horizontally into east face of pier between gates of west spillway, 2 ft from nose of pier, 3-1/2 ft up from floor.	1/2 to 1 2 to 2-1/2 4 to 4-1/2 8 to 8-1/2 16 to 16-1/2 24 to 24-1/2	62 97 98 98 98 98
CE	Sampled horizontally into west face of right buttress, 4 ft up from ground level. Area protected from rainfall by roof of dome.	1/2 to 1 2 to 2-1/2 4 to 4-1/2 8 to 8-1/2 16 to 16-1/2 24 to 24-1/2	26 34 55 58 84 91

*Relative humidity referenced to 70 to 75°F.

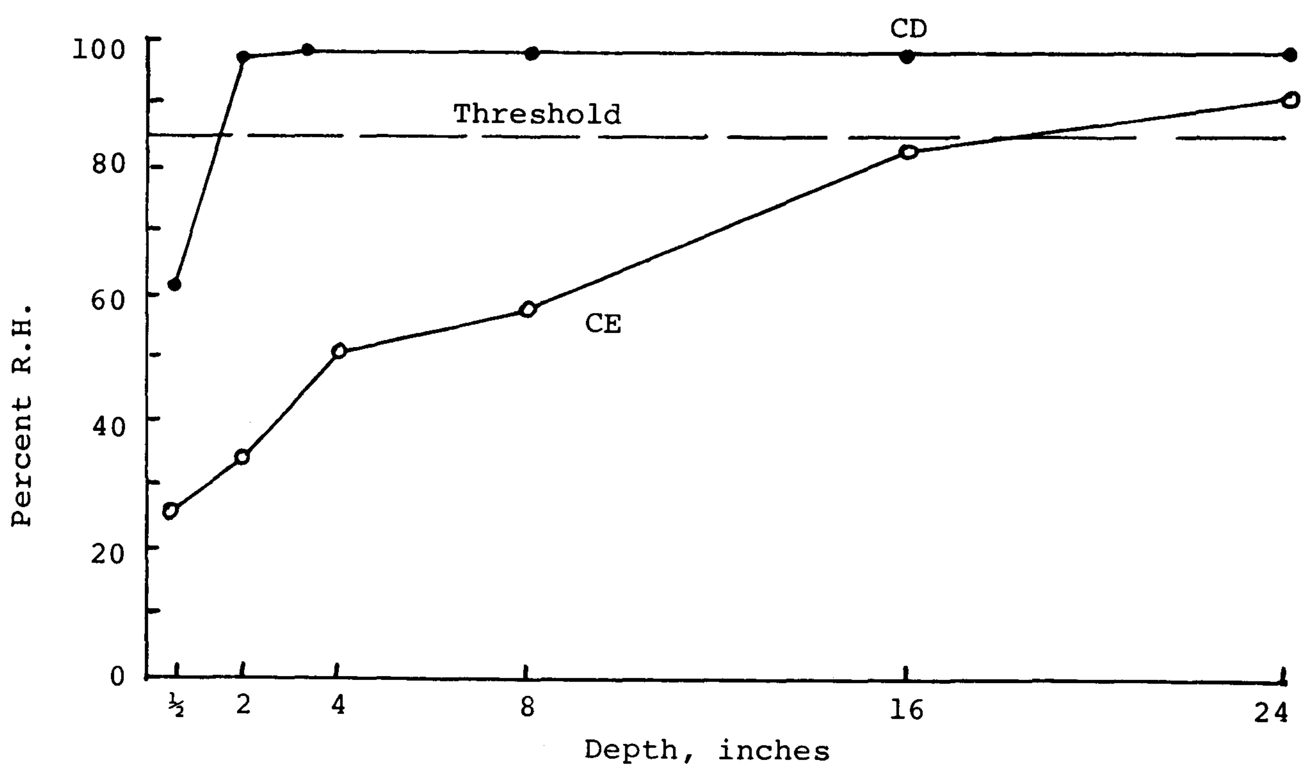

FIG. A2 - RELATIVE HUMIDITY DATA FOR COOLIDGE DAM

FIGURE A3 - PETROGRAPHIC EXAMINATION OF CORES FROM COOLIDGE DAM

Core No.	Core Location, Surface Condition of Concrete	Depth Examined in.	Observations
CA	Vertical core over pier, east edge of spillway, west edge of west dome, midway between columns at ends of parapet wall, 5 ft from curb. Concrete surface displays map cracking.	3-11	Coarse aggregate consists primarily of andesitic to rhyolitic material with lesser amounts of granitic to dioritic material. Maximum particle size in the core section was 1-1/2-in. Fine aggregate consists primarily of feldspar and similar volcanic rocks, with lesser amounts of quartz. Most coarse and fine volcanic particles contain well-defined reaction rims and internal cracks that are lined with alkali-silica gel. Many of these cracks extend into surrounding mortar. Also, the cracks in the mortar and numerous aggregate sockets are lined with gel. Particles of both coarse and fine aggregate have reacted sufficiently to produce cracks that extend throughout the concrete. There was no evidence of other forms of progressive deterioration.
CD	Horizontal core into pier between gates of west spillway, east face. Core taken 3-1/2 ft up from floor of spillway, 2 ft from nose of pier.	0-12	Coarse aggregate consists of about equal proportions of granitic and andesitic to rhyolitic material, with minor amounts of sandstone and limestone. Maximum particle size is 1-1/4 in. The fine aggregate consists of about equal proportions of basaltic to rhyolitic volcanic material, and quartz and feldspar. The top surface of the core displays a crack which extends longitudinally to a depth of about 3-1/2 in. where it terminates at the periphery of a granite coarse aggregate particle. The crack is not associated with any apparent form of deterioration. One coarse rhyolite particle displays a well-defined reaction rim but there is no associated cracking. There is otherwise no evidence of alkali-silica reactivity

FIGURE A3 - PETROGRAPHIC EXAMINATION OF CORES FROM COOLIDGE DAM (Continued)

Core No.	Core Location, Surface Condition of Concrete	Depth Examined in.	Observations
CD	(continued)		in the core. No reaction rims were found on other particles, nor was alkali-silica gel found. No cracking was found that could be associated with reactivity. There was no evidence of other forms of progressive deterioration.
CE	Horizontal core in west face of right buttress, 4 ft up from ground level.	0-6	Coarse aggregate consists of about equal proportions of granitic and andesitic to rhyolitic volcanic material and sandstone. Maximum particle size was 1 in. The fine aggregate consists primarily of feldspar and quartz with minor amounts of granite and volcanic material. Faint reaction rims were observed on two coarse andesite particles, but there was otherwise no evidence of alkali-silica reactivity. There was no evidence of other forms of progressive deterioration.

FIGURE A4 - LENGTH CHANGE OF COOLIDGE DAM CORES IMMERSED IN WATER OR IN NaOH SOLUTION AT 100°F

Core No.	Core Length	Location	Depth in.	Test Sol'n	Percent Length Change									
					7D	14D	1 Mo.	2 Mo	3 Mo.	4 Mo.	5 Mo.	6 Mo.	7 Mo.	8 Mo.
CA-1	6 in.	Over pier, east edge of spillway, west edge of west dome, end of parapet wall, 5 ft from curb.	3-9	H_2O	.018	.010	.015	.012	.017	.015	.017	.015	.018	.017
CA-2	6 in.		15-21	NaOH	.020	.020	.022	.023	.023	.027	.025	.025	.032	.032
CB-1	6 in.	Roadway east of spillway, 10 ft east of pier, 5 ft from curb, eastbound lane.	5-11	H_2O	.017	.018	.017	.018	.020	.023	.020	.020	.023	.022
CB-2	6 in.		5-11	NaOH	.035	.040	.062	.070	.162	.290	.321	.345	.380	.380
CD-1	6 in.	East face of pier between gates of west spillway, 2 ft from nose of pier, 3-1/2 ft up from floor.	15-21	H_2O	.025	.020	.022	.023	.020	.027	.025	.025	.027	.026
CD-2	6 in.		13-19	NaOH	.020	.020	.027	.027	.038	.052	.060	.073	.082	.082
CE-1	6 in.	West face of right buttress, 4 ft up from ground level.	0-6	H_2O	.007	.003	.003	.005	.002	.003	.003	.005	.008	.008
CE-2	6 in.		0-6	NaOH	.003	.008	.008	.018	.027	.087	.108	.140	.163	.064
CE-3	6 in.		13-19	NaOH	.027	.022	.023	.023	.037	.052	.057	.087	.103	.105

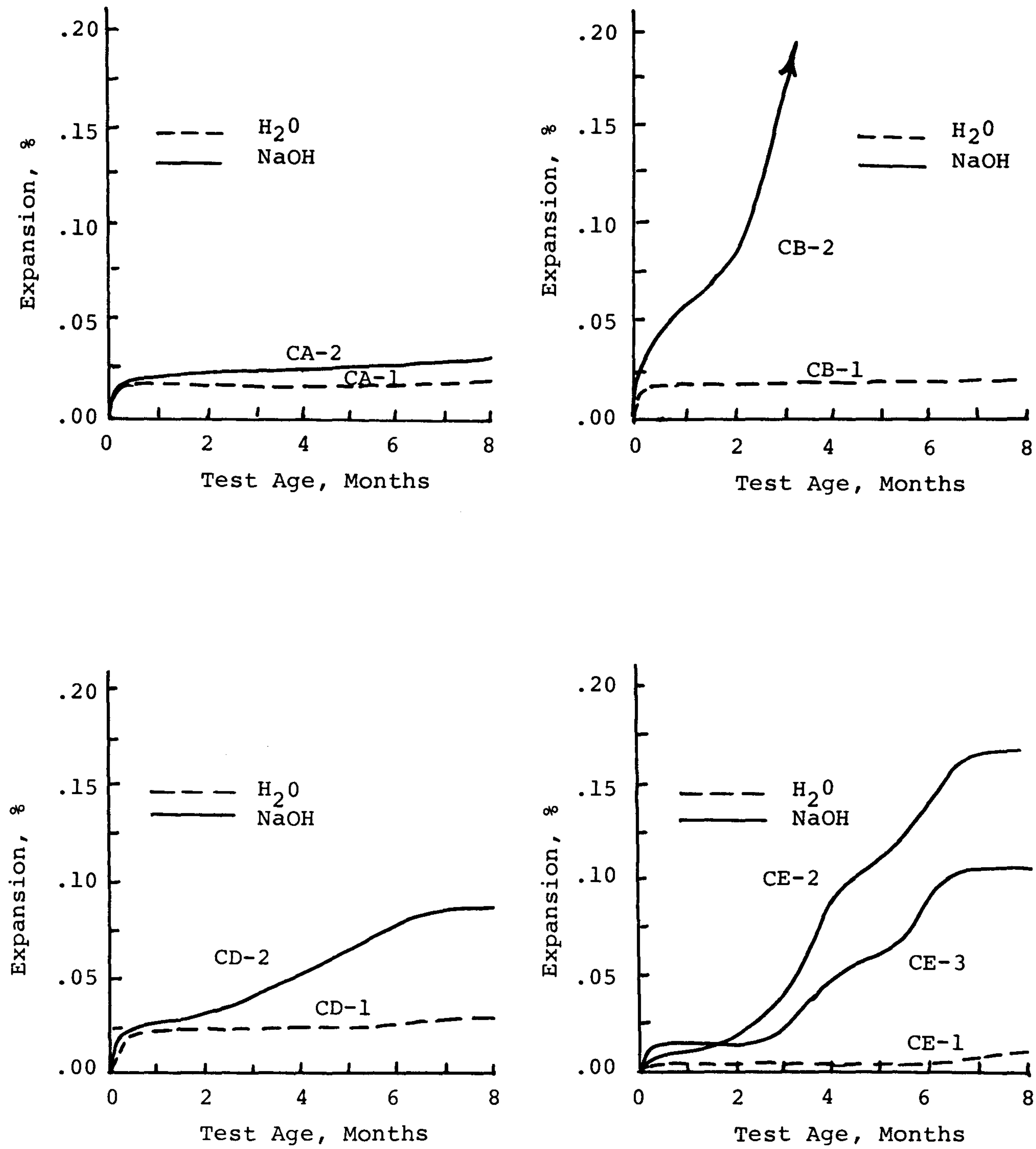

FIG. A5 - LENGTH CHANGES OF COOLIDGE DAM CORES IMMERSED IN WATER OR 1N NaOH SOLUTION AT 100°F

NO.	LOCATION	DESCRIPTION	FLOW RATE, mm/DAY
CE-1	3 to 5 in. from exterior end of core CE, taken into west face of right buttress, 4 ft up from ground level.	Dense crystalline, purple-red andesite porphyry, 3-in. particle. No evidence of previous reactivity.	<0.0
CE-2	Same core as above. Particle located 1 to 3 in. from external surface.	Somewhat weathered and porous, purple-red andesite porphyry. 2-1/2-in. particle size. No evidence of previous reactivity.	7.3

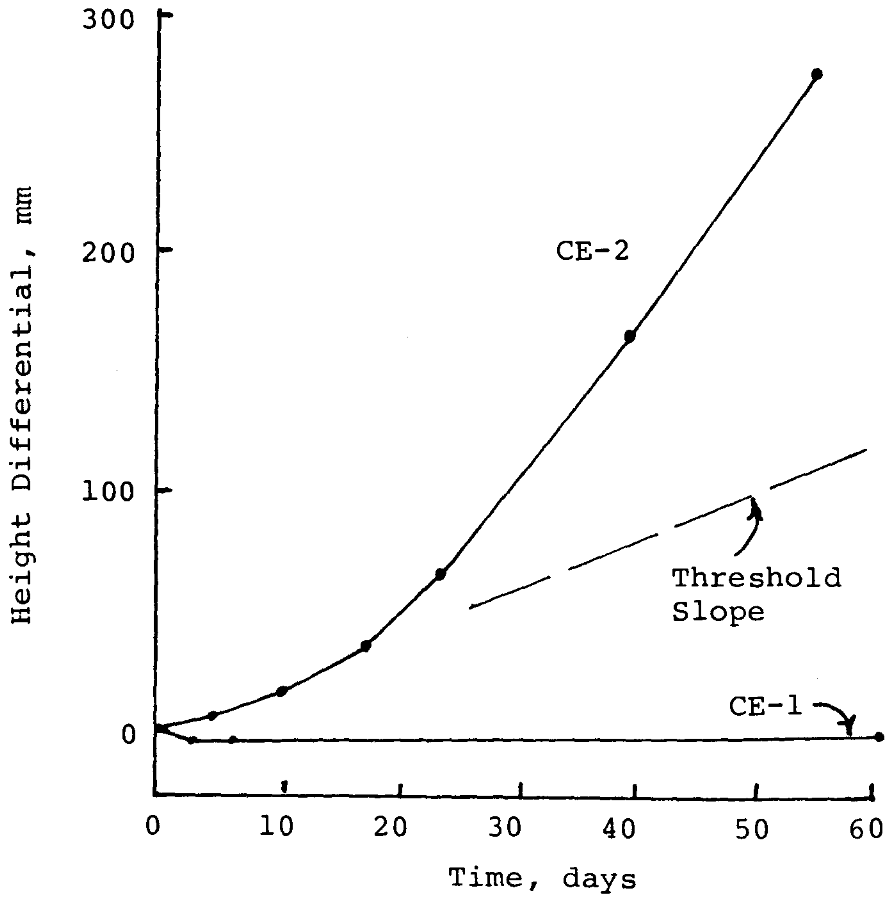

FIG. A6 - RESULTS OF OSMOTIC CELL TESTS FOR AGGREGATE FROM COOLIDGE DAM

APPENDIX B

FRIANT DAM

FIGURES

FRIANT DAM

Background

Friant Dam is located on the San Joaquin River about 20 miles north of Fresno, California. It is a 319-ft high gravity dam completed in 1942.

Locally-derived sand and gravel was used as aggregate. Petrographic examination revealed the coarse aggregate to consist of a wide range of igneous and metamorphic rock types, including andesite and trachyte, latite, and rhyolite. The latter rock types are known to have reacted deleteriously in concrete. The fine aggregate consisted of about 50% quartz with lesser amounts of feldspar and magnetite. volcanic materials were virtually absent in the fine aggregate.

Both high- and low-alkali cements were used in the concrete. A portion of the concrete not specifically delineated in available literature contained a natural pozzolan "pumicite", which was described as a pumiceous rhyolitic vitrophyre.

Within several years after placement, concrete in parts of the dam developed abnormal cracking. Examination of cores indicated that alkali-silica reactivity involving andesite particles had developed. It was further reported that "observable differences among...specimens of both high- and low-alkali cores, with and without pumicite...are not as great as might have been anticipated." This was in reference primarily to the presence of clarified rims on aggregates. Thus, deleterious alkali-silica reactivity is known to have been present in Friant Dam virtually since the time of construction.

Inspection of dam during this investigation revealed widely varying degrees of visible cracking. Severe cracking was observed in the concrete stairway near the ground level viewing area, in the concrete blocks adjacent to the gates, and in curbs and walkways along the roadway at the top of the dam. The down-stream face of the dam displayed only faint localized map-cracking. Concrete observed in the lower galleries was free of visible cracking. Severe but very limited cracking was observed around the Friant-Kern and Mødera outlet structures.

SAMPLE	LOCATION	DEPTH IN.	R.H.* %
FA	Sampled horizontally into downstream face of dam, 4 ft up from platform at top of outlet gatehouse, 20 ft from railing.	1/2 to 1 2 to 2-1/2 4 to 4-1/2 8 to 8-1/2 16 to 16-1/2 24 to 24-1/2	45 85 89 89 92 90
FB	Sampled vertically into tread at eighth step up on stairway leading to gravel viewing area near base of spillway.	1/2 to 1 2 to 2-1/2 4 to 4-1/2 8 to 8-1/2 16 to 16-1/2 24 to 24-1/2	96 97 98 99 100 100
FC	Sampled horizontally into 1 ft thick wall at viewing area adjacent to east spillway, 20 ft from spillway wall.	1/2 to 1 2 to 2-1/2 4 to 4-1/2 6 to 6-1/2	90 95 95 97

*Relative humidity referenced to 70 to 75°F.

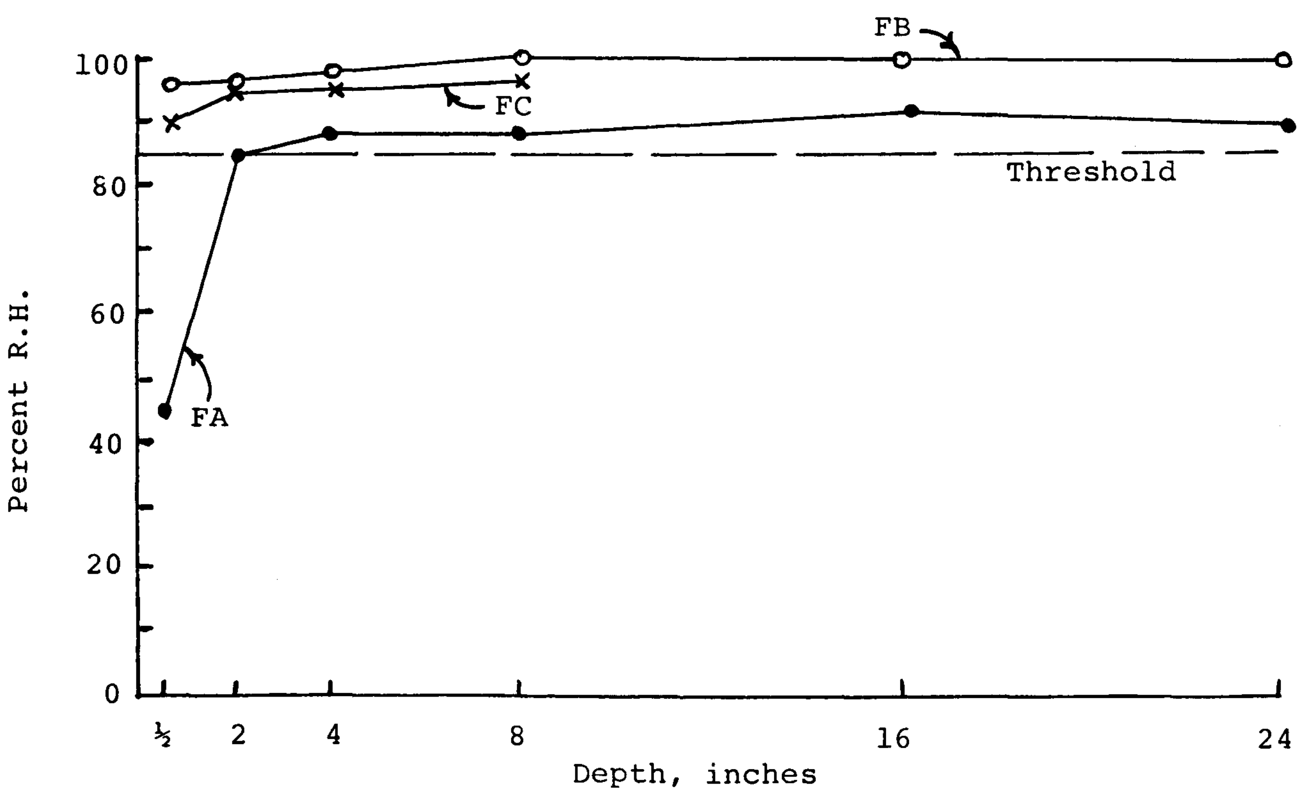

FIG. B1 - RELATIVE HUMIDITY DATA FOR FRIANT DAM

SAMPLE	LOCATION	DEPTH IN.	R.H.* %
FD	Sampled horizontally into downstream face of dam, near Friant-Kern outlet, 12 ft north of gallery door, 3-1/2 ft above ground level at roadway.	1/2 to 1 2 to 2-1/2 4 to 4-1/2 8 to 8-1/2 16 to 16-1/2 24 to 24-1/2	63 96 95 98 99 99
FE	Sampled vertically into roadway at top of dam, in block adjacent to spillway, 5 ft from wall.	1/2 to 1 2 to 2-1/2 4 to 4-1/2 8 to 8-1/2 16 to 16-1/2 24 to 24-1/2	92 94 98 99 100 100
FF	Sampled horizontally into roadway at top of dam, in slab abutting block adjacent to spillway, 20 ft south of joint between slab and block.	1/2 to 1 2 to 2-1/2 4 to 4-1/2 8 to 8-1/2 16 to 16-1/2 24 to 24-1/2	78 87 97 95 95 97

*Relative humidity referenced to 70 to 75°F.

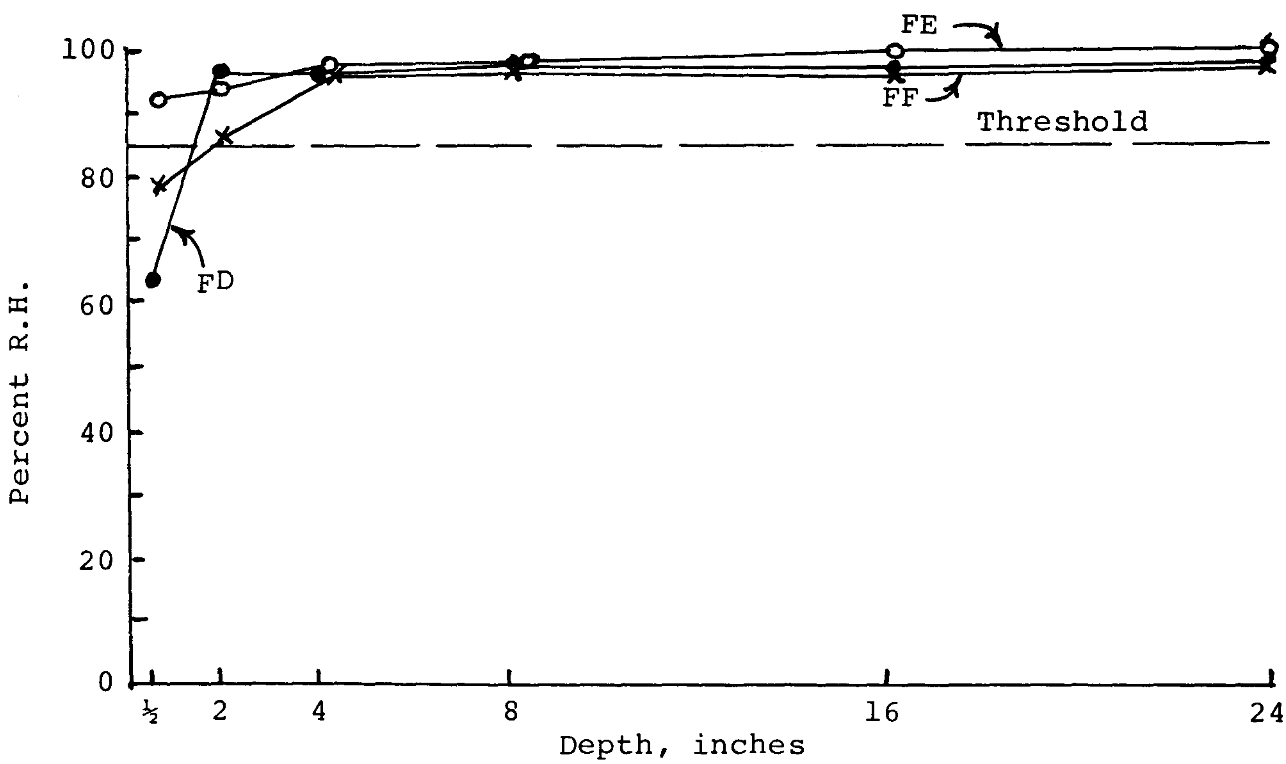

FIG. B2 - RELATIVE HUMIDITY DATA FOR FRIANT DAM

FIGURE B3 - PETROGRAPHIC EXAMINATION OF CORES FROM FRIANT DAM

Core No.	Core Location, Surface Condition of Concrete	Depth Examined in.	Observations
FA	Horizontal core taken into face of dam, 4 ft above platform, 20 ft from railing, at top of outlet gatehouse. Concrete surface free of visible cracking.	12-20	Coarse aggregate consists primarily of acid to intermediate volcanics, with minor amounts of granitic and quartzose rock types. One 4-in. andesite particle is present. Other coarse aggregate particles are less than 1-1/2 in. Most intermediate volcanics (andesites), except the 4 in. particle, display well defined reaction rims, but there is no microcracking on or associated with these particles, nor was alkali-silica gel observed. The fine aggregate is primarily quartz, feldspar, and volcanics. Overall, there is no evidence of alkali-silica reactivity in this core. Traces of ettringite were observed in entrapped air voids. There was no evidence of any type of progressive deterioration in this core.
FB	Horizontal core taken into side of concrete stairway block, 7th step up from ground level, adjacent to gravel area, east spillway. Concrete surface displays severe map cracking.	28-36	Coarse aggregate consists primarily of intermediate volcanic rock types. Few granitic, dioritic and quartzite particles also are present. One 3-in. andesite particle is present. Other coarse aggregate particles are less than 1-1/2 in. Sand consists of quartz and feldspar with lesser amounts of volcanics. The volcanic particles, particularly andesites display reaction rims. Most of these particles contain microcracks that extend into surrounding mortar. Other microcracks also are present but their origin could not be determined. Microcracks in the 3-in. andesite particle contains deposits of alkali-silica gel. Examination of freshly fractured surfaces revealed the presence of large amounts of alkali-silica gel within andesite aggregate particles, in entrapped air voids and on fractured surfaces. Much of the

FIGURE B3 - PETROGRAPHIC EXAMINATION OF CORES FROM FRIANT DAM (Continued)

Core No.	Core Location, Surface Condition of Concrete	Depth Examined in.	Observations
FB	(continued)		gel is partially carbonated. A few secondary ettringite deposits also were observed on existing fractured surfaces.
FE	Core taken vertically on roadway on dam, Friant side, in block adjacent to spillway, 5 ft from wall. Concrete displays map-cracking.	18-27	Coarse aggregate consists primarily of acid to intermediate volcanics, with lesser amounts of granitic material and quartzite. Maximum particle size in this core section was 1-1/4 in. The fine aggregate consists primarily of quartz and feldspar with lesser amounts of volcanics. Most coarse andesite to rhyolite particles displayed well-defined reactions rims, and contain numerous microcracks which extend into surrounding mortar. Many of these cracks are lined with alkali-silica gel. Some of the gel is partially carbonated. Volcanic particles in the fine aggregate show similar features of reactivity. Several cracks extend completely across the core. Their origin could not be determined. Overall, concrete in this core has experienced severe alkali-silica reactivity with associated cracking. There was no evidence of other forms of progressive deterioration.
FF	Vertical core taken in middle of roadway on dam, 20 ft south of block adjacent to spillway on Friant side. There was no cracking evident on concrete surface. But minor map-cracking occurs along joint adjacent	0-8	Coarse aggregate in the 0 to 8" core section consists primarily of granitic material, with lesser amounts of quartzite and acid to intermediate volcanics. Maximum particle size was 1-1/8-in. Fine aggregate consists of quartz, feldspar, and minor amounts of volcanics. A few volcanic particles in the -1/2 in. size range display reaction rims and contain a few microcracks partially lined with alkali-silica gel. Some of these

FIGURE B3 - PETROGRAPHIC EXAMINATION OF CORES FROM FRIANT DAM (Continued)

Core No.	Core Location, Surface Condition of Concrete	Depth Examined in.	Observations
FF	to block in which core FE was taken.		cracks extend a short distance into surrounding mortar. Gel deposits also occur in a few entrapped air voids. Overall, this core displays only very minor microcracking and evidence of reactivity, compared with Core FE. This corresponds to a reduced proportion of volcanic material in core FF.
		38-44	In the 38 to 44" core section, the coarse and fine aggregate are similar to that in the 0 to 8" section. An occasional entrapped air void contains a lining of alkali-silica gel. There was no evidence of microcracking that could be associated with alkali-aggregate reactivity. Traces of ettringite were observed in several entrapped air voids. There was no evidence of other forms of progressive deterioration.

FIGURE B4 - LENGTH CHANGE OF FRIANT DAM CORES IMMERSED IN WATER OR IN NaOH SOLUTION AT 100°F

Core No.	Core Length	Location	Depth in.	Test Sol'n	Percent Length Change									
					7D	14D	1 Mo.	2 Mo	3 Mo.	4 Mo.	5 Mo.	6 Mo.	7 Mo.	8 Mo.
FA-1	9 in.	Face of dam, 4 ft above platform at outlet gatehouse.	26-35	H_2O	.003	.004	.006	.006	.006	.005	.005	.005	.005	.004
FA-2	5 in.		39-44	NaOH	.012	.006	.014	.018	.020	.020	.016	.024	.024	.023
FD-1	9 in.	Face of dam, near Friant-Kern outlet, 12 ft north of gallery.	26-35	H_2O	.016	.018	.016	.018	.018	.020	.017	.017	.017	.017
FD-2	9 in.		26-35	NaOH	.024	.022	.023	.026	.030	.034	.028	.029	.031	.031
FF-1	6 in.	Roadway on dam, in slab abutting block adjacent to spillway.	10-16	H_2O	.022	.028	.033	.040	.040	.045	.029	.045	.043	.043
FF-2	9 in.		19-28	NaOH	.016	.017	.019	.017	.013	.018	.020	.024	.021	.021

FIG. B5 - LENGTH CHANGES OF FRIANT DAM CORES IMMERSED IN WATER OR 1N NaOH SOLUTION AT 100°F

NO.	LOCATION	DESCRIPTION	FLOW RATE, mm/DAY
FA-1	At 15-19 in. depth from exterior end of core FA, taken into downstream face of dam 4 ft above platform at top of outlet gate-house, 20 ft from railing.	Dense, mottled white and brown andesite. No evidence of previous reactivity.	0.6
FB-1	At 30-34 in. depth from exterior end of core FB, taken into tread at eighth step up on stairway leading to viewing area near base of spillway.	Light brown andesite, 4-in. particle contained reaction rim, alkali-silica gel, and microcracking, which are evidence of previous deleterious alkali-silica reactivity.	6.7

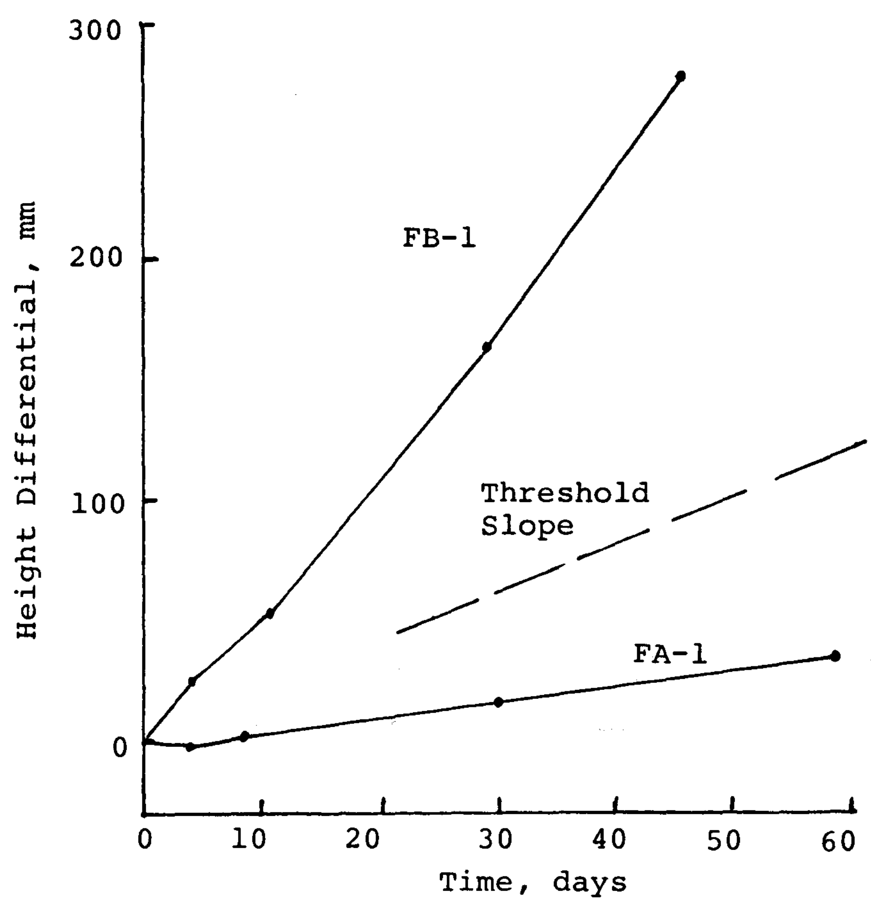

FIG. B6 - RESULTS OF OSMOTIC CELL TESTS FOR AGGREGATE FROM FRIANT DAM

APPENDIX C

MATILIJA DAM

FIGURES

MATILIJA DAM

Background

Matilija Dam is located on Matilija Creek, approximately 15 miles north of Ventura, California. This structure, completed in 1949, is a single arch dam standing 163 ft high.

Information on material used in the concrete are somewhat lacking. The alkali content of the cement was not reported, and the source of coarse aggregate is unknown, but the fine aggregate was reported to have been obtained from near Saticoy, California.

Concern over abnormal cracking and the structural integrity of the dam developed in the early 1960's. Severe map- and random cracking had developed, particularly in upper levels of the arch structure. Subsequent remedial measures included removal of the upper middle section of the dam. It was stated during the present inspection (1984) that severity of cracking had increased significantly after removal of the concrete.

Survey of the structure during this investigation revealed severe random, diagonal and map-cracking in the upper one-third to one-half of the arch structure, and differential movement of concrete slabs and other units. Diagonal cracking was the predominant form of distress in the arch structure near the abutments. The lower half of the dam displayed little or no abnormal cracking.

SAMPLE	LOCATION	DEPTH IN.	R.H.* %
MA	Sampled horizontally into retaining wall along walkway at roadway level, 4 ft above platform.	1/2 to 1 2 to 2-1/2 4 to 4-1/2 8 to 8-1/2 16 to 16-1/2	62 98 100 100 100
MB	Sampled horizontally into 8-in. thick railing on stairway at second landing, 15 in. below top of stairway.	1/2 to 1 2 to 2-1/2 4 to 4-1/2 7 to 7-1/2	90 95 95 86
MD	Sampled vertically into fifth step up from first landing of stairway.	1/2 to 1 2 to 2-1/2 4 to 4-1/2 8 to 8-1/2 16 to 16-1/2	85 90 96 100 100

*Relative humidity referenced to 70 to 75°F.

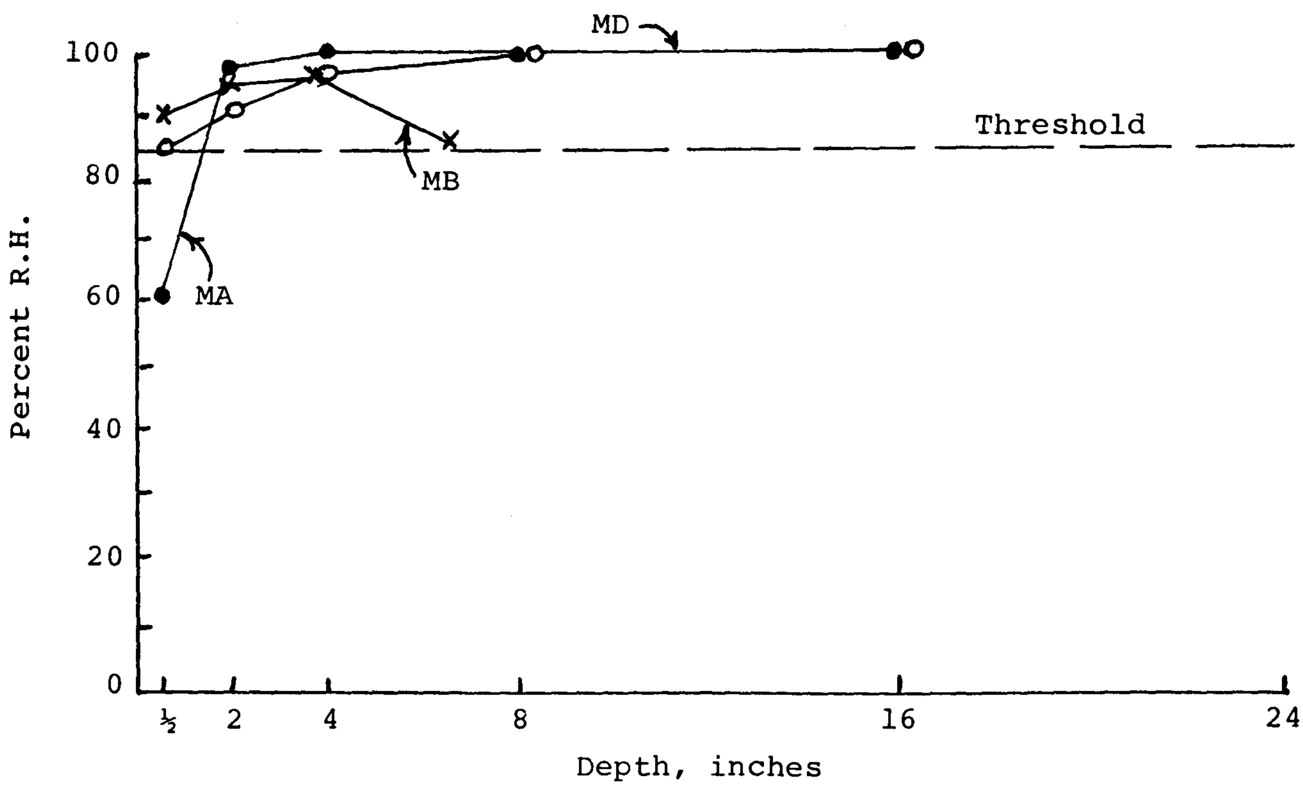

FIG. C1 - RELATIVE HUMIDITY DATA FOR MATILIJA DAM

SAMPLE	LOCATION	DEPTH IN.	R.H.* %
MC	Sampled horizontally into downstream face of dam, 3 ft above second landing of stairway.	1/2 to 1 2 to 2-1/2 4 to 4-1/2 8 to 8-1/2 16 to 16-1/2 24 to 24-1/2	93 98 100 100 100 100
ME	Sampled horizontally into downstream face of dam, 3 ft above lower platform.	1/2 to 1 2 to 2-1/2 4 to 4-1/2 8 to 8-1/2 16 to 16-1/2	100 97 97 97 100

*Relative humidity referenced to 70 to 75°F.

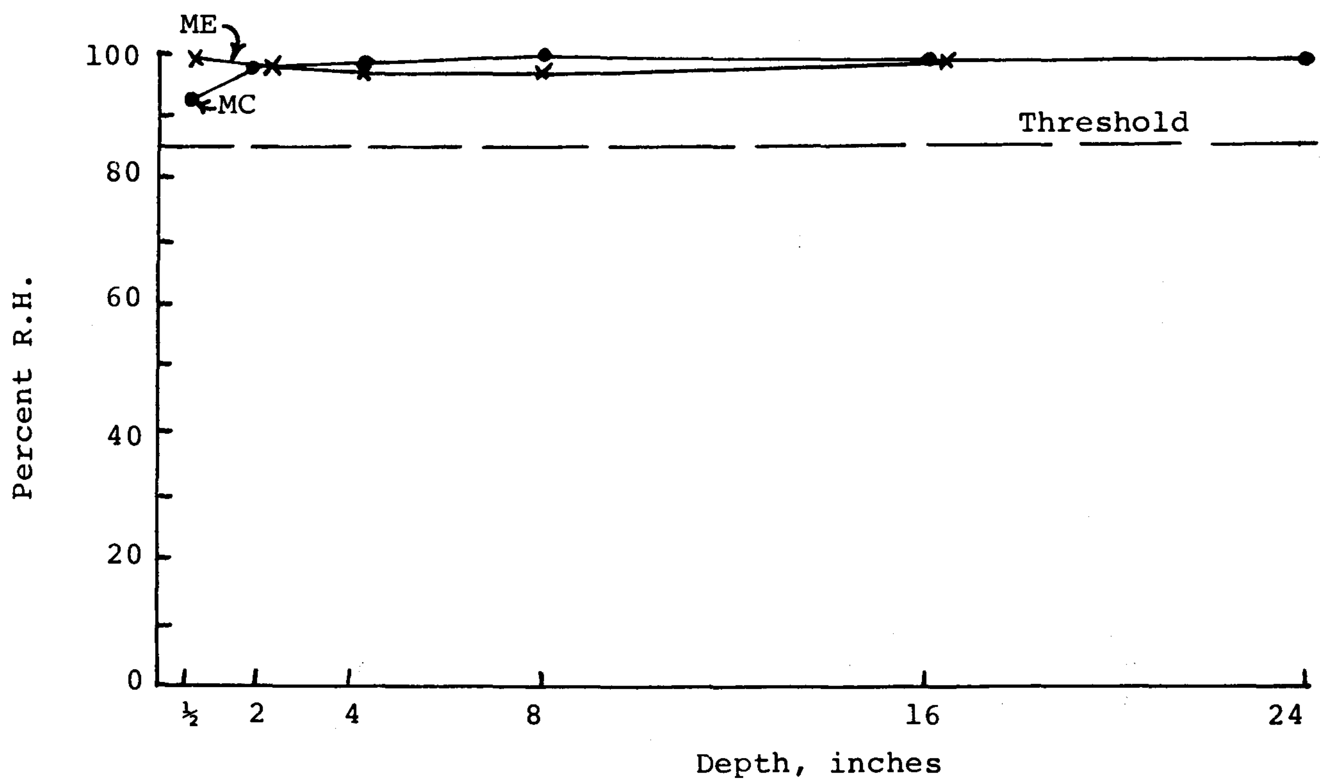

FIG. C2 - RELATIVE HUMIDITY DATA FOR MATILIJA DAM

FIGURE C3 - PETROGRAPHIC EXAMINATION OF CORES FROM MATILIJA DAM

Core No.	Core Location, Surface Condition of Concrete	Depth Examined in.	Observations
MC-3	Horizontal core taken into south fare at east end of dam, 3 ft above second landing of stairway. Concrete displays severe map and diagonal cracking.	0-10	Coarse aggregate consists primarily of granitic material with lesser amounts of hornfels, gabbro, siltstone, and intermediate to acid volcanic rock types. Maximum particle size was 1 in. Fine aggregate consists primarily of quartz and feldspar, with lesser amounts of shale, volcanics, and granitic material. This core section is severely cracked, with the more prominent cracks extending traversely across the core. Microcracks also are present which interconnect with the more prominent transverse cracks. Numerous microcracks were found to extend radially away from highly altered coarse sand particles. These particles now consist largely of alkali-silica gel and appear originally to have been shales. These particles appear to constitute about 5 to 10% of the - 4 + 16 sieve fraction of aggregate particles. Gel also occurs in entrapped air voids and on surfaces of existing fractures. Reaction rims occur on certain hornfels particles, but there was no gel or cracking associated with these particles. There was no evidence of other forms of progressive deterioration.
ME-1	Horizontal core taken into south face of dam, east side of stream, 3 ft up from lower platform. Concrete surface displayed localized,	24-32	Coarse aggregate consists primarily of granitic material and hornfels, with minor chert. Maximum particle size was 1-1/4 in. The fine aggregate consists primarily of quartz and feldspar, with lesser amounts of shale. This core section contains a longitudinal crack that extends the full length of the section. It interconnects with several

FIGURE C3 - PETROGRAPHIC EXAMINATION OF CORES FROM MATILIJA DAM (Continued)

Core No.	Core Location, Surface Condition of Concrete	Depth Examined in.	Observations
ME-1	Minor random cracking.		transverse microcracks, the origins of which could not be determined. Numerous coarse sand size shale particles were highly altered and contain alkali-silica gel. Microcracks extend radially outward from these particles a short distance into surrounding mortar. The same particles also contain interconnecting microcracks that extend into surrounding mortar. The longitudinal crack is partially lined with gel, with particular accumulation in coarse aggregate sockets. None of the coarse aggregate particles appear to have reacted. Most of the gel deposits are concentrated in and around reacted shale particles. Quantity of gel observed is much less, and cracking is less severe than in core MC-3. There was no other form of progressive deterioration noted.

Core No.	Core Length	Location	Depth ft	Test Sol'n	Percent Length Change									
					7D	14D	1 Mo.	2 Mo	3 Mo.	4 Mo.	5 Mo.	6 Mo.	7 Mo.	8 Mo.
M-A1	9 in.	Vertically into dam. Cores retrieved from 1975 stockpile.	160 to 170	H_2O	.028	.026	.027	.031	.029	.029	.030	.030	.033	.030
M-A2	9 in.			NaOH	.027	.029	.033	.061	.236	.400	.451	.463	.478	.479

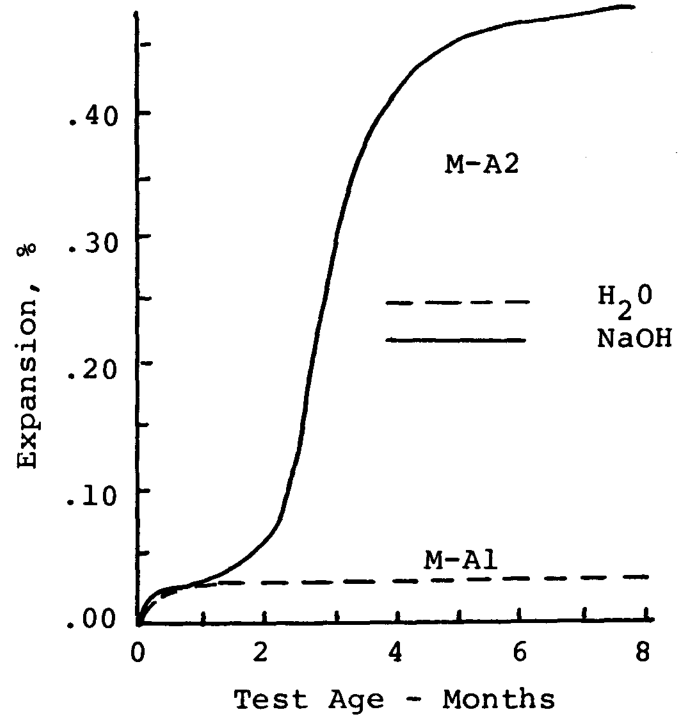

FIG. C4 - LENGTH CHANGE OF MATILIJA DAM CORES IMMERSED IN WATER OR 1N NaOH SOLUTION AT 100°F

APPENDIX D

PARKER DAM

FIGURES

PARKER DAM

Background

Parker Dam is a 325-ft high structure located on the Colorado River about 50 miles southeast of Needles, California. It was built during the period of 1936 to 1938, and consists of an arch structure below the spillways and a series of gravity sections between spillway gates in the upper portion.

The dam was built using aggregates from near the confluence of the Colorado and Bill Williams Rivers. Portland cement with up to 1.2%, alkali as equivalent Na_2O was reported to have been utilized in the dam structure. By 1938, abnormal cracking was reported in parts of the dam and in 1940, cores were obtained for examination to determine the cause of the observed distress. The examination confirmed the development of alkali-silica reactivity as gel reaction products were found to be associated with andesite and rhyolite aggregate particles.

Inspection of the dam during this investigation confirmed the development of expansion and abnormal cracking in the concrete. Severe map- and random cracking were apparent along the walkway and retaining wall at the roadway level on the dam. The superstructure also displayed various abnormal crack patterns. Concrete at approximately the level of the spillway floor and lower did not display abnormal cracking.

Inspection of the exterior surface of the walls of the powerhouse revealed the presence of map-cracking. On the north side, clear dark-gray band bordered each crack segment. It was judged, from past experience, to have been caused by deposition of clear alkali-silica gel. This condition was not seen on the southwall, and may thus be related to differences in exposure to direct sunlight. The powerhouse was reported to have been built with low-alkali cement after discovery of alkali-silica reactivity in the dam structure.

SAMPLE	LOCATION	DEPTH IN.	R.H.* %
PA	Sampled vertically into walkway, 60 ft west of west column of superstructure, 10 ft from edge of roadway.	1/2 to 1 2 to 2-1/2 4 to 4-1/2 8 to 8-1/2 16 to 16-1/2 24 to 24-1/2	40 92 97 97 98 100
PB	Sampled vertically into walkway at roadway level east side of west spillway, 9 ft from roadway.	1/2 to 1 2 to 2-1/2 4 to 4-1/2 8 to 8-1/2 16 to 16-1/2 24 to 24-1/2	90 98 99 98 100 98
PC	Sampled horizontally into east face of east column of west spillway, 3-1/2 ft up from walkway. Encountered rebar at 6-in. depth.	1/2 to 1 2 to 2-1/2 4 to 4-1/2	10 30 47

*Relative humidity referenced to 70 to 75°F.

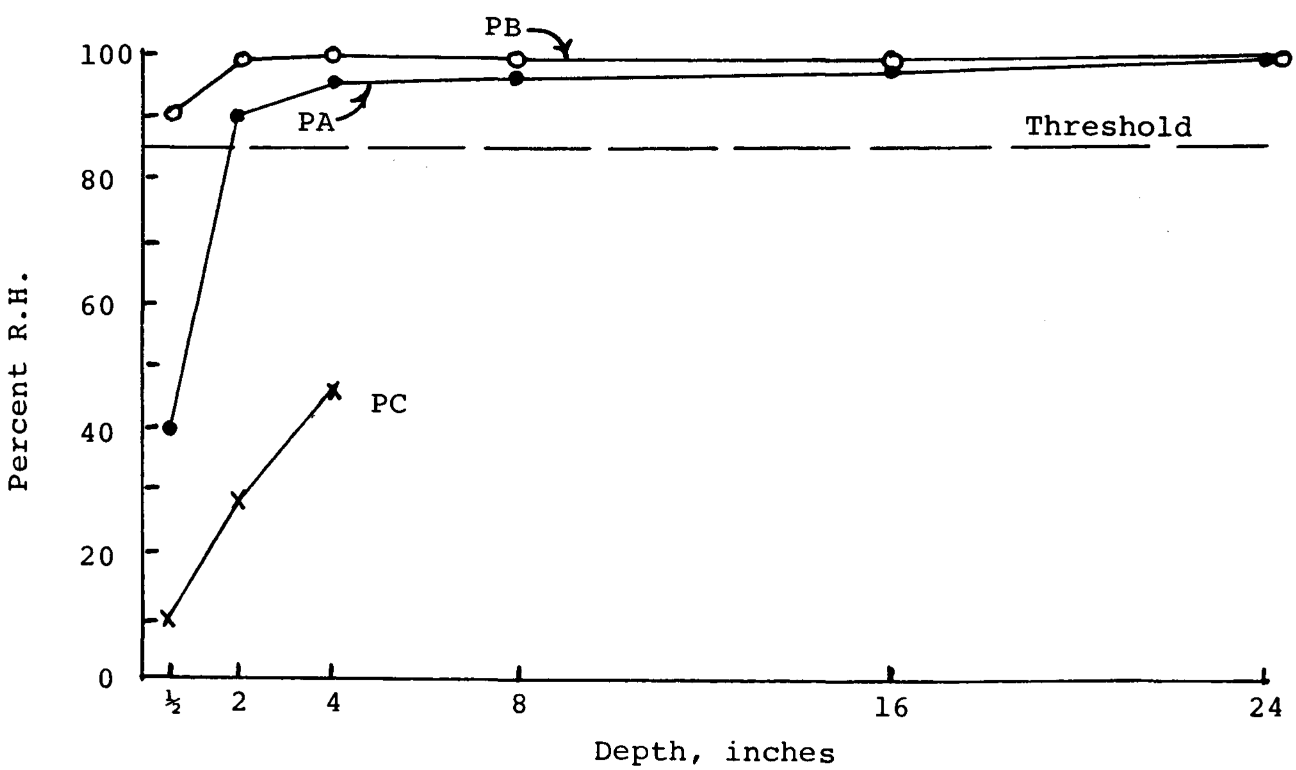

FIG. D1 - RELATIVE HUMIDITY DATA FOR PARKER DAM

SAMPLE	LOCATION	DEPTH IN.	R.H.* %
PD	Sampled vertically into center of 5 ft square concrete block at east end of wall on north side of roadway.	1/2 to 1 2 to 2-1/2 4 to 4-1/2 8 to 8-1/2 16 to 16-1/2 24 to 24-1/2	34 91 95 98 99 99
PE	Sampled from outside surface horizontally into north wall of powerhouse, 30 ft from northeast corner, 4 ft up from walkway level. Wall is 2 ft thick with bare exterior surface and painted interior surface.	1/2 to 1 2 to 2-1/2 4 to 4-1/2 8 to 8-1/2 16 to 16-1/2	32 47 57 70 70

*Relative humidity referenced to 70 to 75°F.

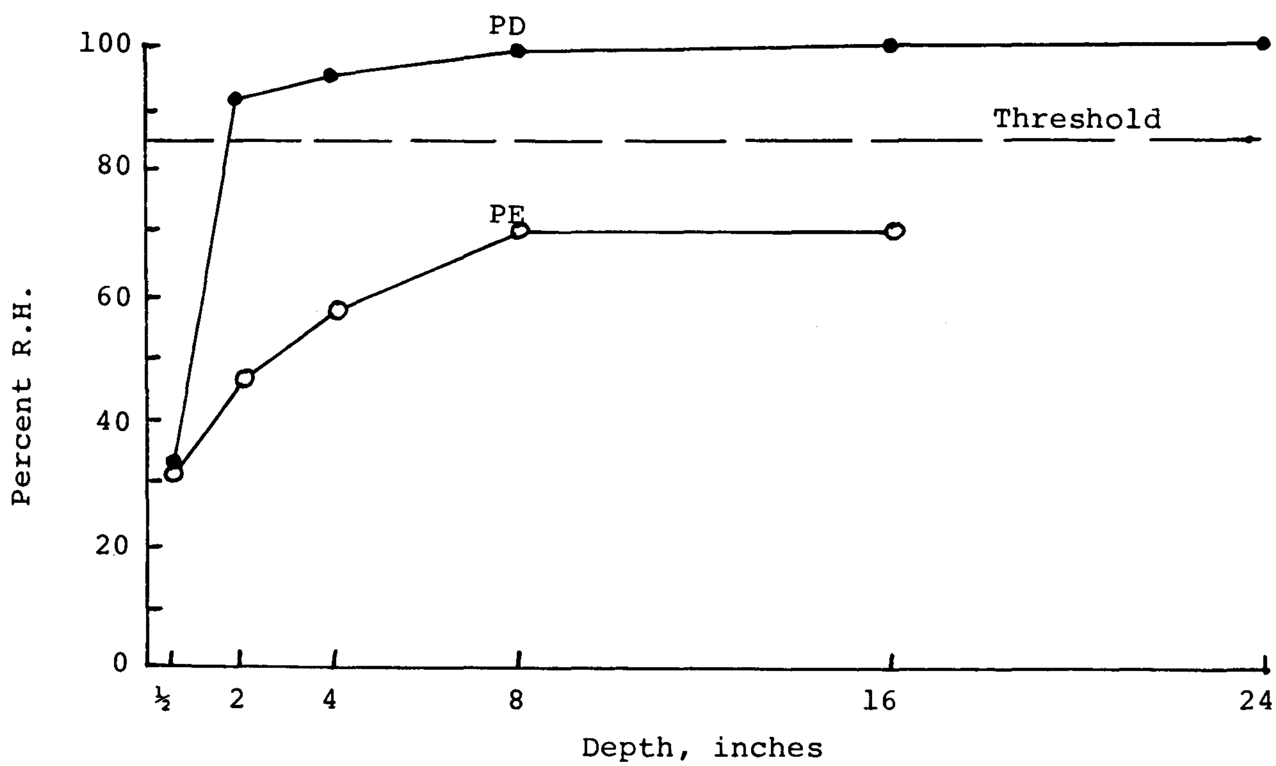

FIG. D2 - RELATIVE HUMIDITY DATA FOR PARKER DAM

FIGURE D3 - PETROGRAPHIC EXAMINATION OF CORES FROM PARKER DAM

Core No.	Core Location, Surface Condition of Concrete	Depth Examined in.	Observations
PDE-1B	Vertical core into "monument" at east end of wall, east end of dam. Concrete surface displays severe map cracking.	3-12	Coarse aggregate consists of about equal proportions of cryptocrystalline intermediate to acid volcanics (andesite to rhyolite), and quartzose and granitic material. Maximum particle size in the core section is 1-1/2 in. The fine aggregate consists primarily of feldspar and quartz with minor amounts of rhyolite, andesite, and granitic material. Rhyolite and andesite particles displayed well-defined reaction rims, together with microcracks at or just inside the peripheries of the particles. These cracks are filled with alkali-silica gel. Many of these cracks extend at one point into surrounding mortar. The same particles contain cracks that extend transversely across the particles and into surrounding mortar. Large amounts of alkali-silica gel occur in entrapped air voids, in aggregate sockets, in microcracks, and on surfaces of aggregate particles that display no evidence of having reacted. In the latter case, the gel appears to have flowed to these surfaces after cracking developed from surrounding reacted particles. Minor ettringite was found in air voids and aggregate sockets. There was no evidence of other forms of progressive deterioration.
P-CP-2	Core from stockpile, taken from "powerhouse area," but exact location unknown. Top end of core carries coating of white paint. Painted end of core does not display any cracking.	0-9	Coarse aggregate consists primarily of granitic to dioritic rock types, with lesser proportions of schist, quartzite and chert, and andesite to basalt volcanic materials. Traces of rhyolite also are present. Maximum particle size in the core section was 3/4 in. The fine aggregate is of similar composition but with greater proportion of quartz. None of the

FIGURE D3 - PETROGRAPHIC EXAMINATION OF CORES FROM PARKER DAM (continued)

Core No.	Core Location, Surface Condition of Concrete	Depth Examined in.	Observations
P-CP-2	(Continued)		aggregate particles displayed reaction rims or microcracking. No alkali-silica gel was found in this core. Overall, there was no evidence of alkali-silica reactivity or other forms of progressive deterioration.
PDW-1A	Vertical core into sidewalk at west end of dam, 60 ft from west column of superstructure, 10 ft from edge of roadway. Concrete surface displays moderate to severe map cracking. The core was taken through one of the cracks visible on the sidewalk.	0-11	Coarse aggregate consists of about equal proportions of rhyolitic to andesitic volcanic material, and granitic to dioritic rock types. Minor amounts of quartzite, gneiss, and chert also were present. Maximum particle size in this core section is 1 in. The fine aggregate consists primarily of quartz and feldspar with lesser amounts of rhyolite, andesite, and chert. Volcanic particles display well-defined reaction rims. Alkali-silica gel occurs in microcracks in these particles, as well as in entrapped air voids. The core was taken through a crack visible on the surface of the sidewalk. Within the core, this crack extends to a depth of 4 in. and breaks aggregate. At depths of 5 to 11 in. a network of random cracks extends through the concrete. Many of these cracks extend across the core and their origin could not be determined. At depths less than about 4 in., the network of microcracking was absent and essentially only the crack visible at the surface was present. In the 0 to 4 in. depth, there are reaction rims on a few volcanic particles, but only very minor gel deposits. At depths greater than 6 in., gel deposits are numerous and fill entrapped air voids and line existing cracks. The crack visible at the surface contains generally moderate amounts of carbonated alkali-silica gel.

FIGURE D4 - LENGTH CHANGE OF PARKER DAM CORES IMMERSED IN WATER OR IN NaOH SOLUTION AT 100°F

Core No.	Core Length	Location	Depth in.	Test Sol'n	Percent Length Change									
					7D	14D	1 Mo.	2 Mo	3 Mo.	4 Mo.	5 Mo.	6 Mo.	7 Mo.	8 Mo.
P-CP-1	10 in.	From core stockpile.	Not	H_2O	.015	.011	.014	.021	.020	.022	.022	.022	.025	.025
P-CP-3	10 in.		known	NaOH	.016	.018	.018	.029	.031	.033	.042	.047	.065	.082
PDE-1AA	6 in.	"Monument" at east end of wall along roadway on dam.	12-18	H_2O	.025	.025	.038	.030	.032	.028	.025	.027	.030	.028
PDE-1BA	9 in.		13-22	NaOH	.031	.034	.036	.037	.038	.037	.039	.038	.040	.040
PDM-1AA	9 in.	Sidewalk near roadway, east side of west spillway.	0-9	NaOH	.026	.027	.028	.028	.029	.083	.029	.026	.029	.029
PDM-1BA	9 in.		0-9	NaOH	.036	.039	.040	.043	Broken		—	—	—	—
PDM-1BB	9 in.		12-21	NaOH	.024	.030	.029	.029	.031	.024	.024	.027	.030	.031
PDW-1AA	9 in.	Sidewalk near roadway, 60 ft west of west column of superstructure.	12-21	H_2O	.008	.002	.003	.005	.006	.007	.005	.006	.005	.005
PDW-1BA	6 in.		11-17	NaOH	.027	.022	.022	.025	.030	.025	.023	.025	.028	.028

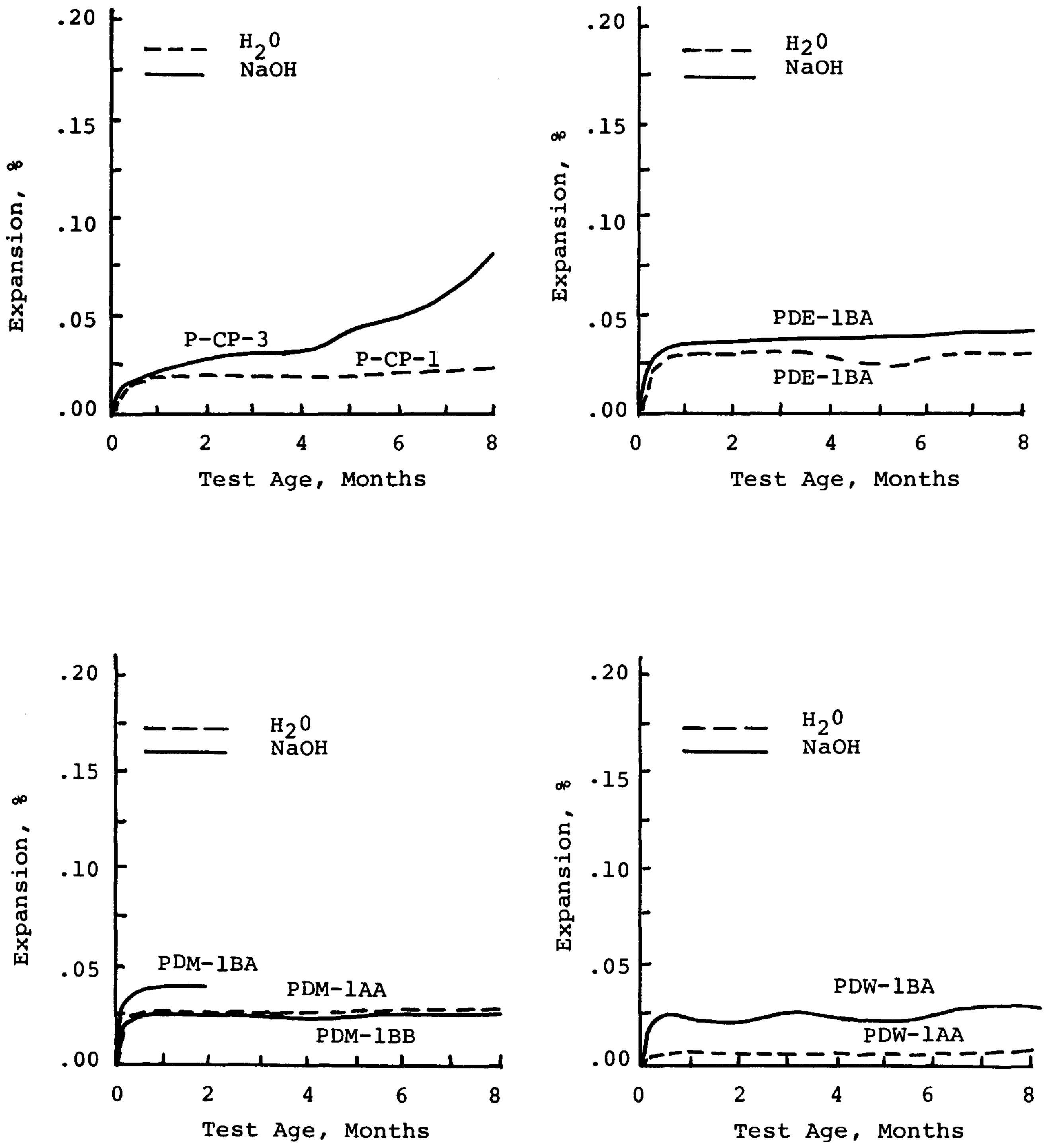

FIG. D5 - LENGTH CHANGES OF PARKER DAM CORES IMMERSED IN WATER OR 1N NaOH SOLUTION AT 100°F

APPENDIX E

STEWART MOUNTAIN DAM

FIGURES

Figure | Page

STEWART MOUNTAIN DAM

Background

Stewart Mountain Dam is located on the Salt river about 35 miles northeast of Phoenix, Arizona, and was built in 1929-1930. It is a 207-ft high variable radius arch dam supported by gravity thrust blocks on either abutment. A short gravity wing connects the arch structure to a gated concrete weir spillway on the left abutment. The concrete in the arch structure was made with portland cement with reported alkali contents greater than 1.0% as equivalent Na_2O, and aggregate from sand and gravel bars in the Salt River stream bed near the dam site.

Evidence of deterioration of concrete in the dam was first reported in 1935, five years after the dam was put into service. It was manifested in progressive crack development, expansion, and deflection. By the 1940's the conclusion was reached that deterioration had been caused by alkali-silica reactivity. This was determined from examination of concrete cores, in which it was noted that reacted aggregate particles were glassy to cryptocrystalline volcanic materials of andesitic to rhyolitic composition. These rock types were reported to be present in the proportion of about 20 to 30% of the total aggregate. Until the early to mid 1960's abnormal upstream movement of the dam was recorded. Since that time the dam was reported to have more or less stabilized.

Inspection of the dam during this investigation revealed the presence of map-cracking and various other random crack patterns in the upper levels of the dam. Cracking was most evident in the roadway and parapet walls at the top of the dam. The powerhouse displayed minor random and diagonal cracking and had separated from the dam. Lower levels of the dam and thrust blocks were free of visible abnormal cracking.

SAMPLE	LOCATION	DEPTH IN.	R.H.* %
SA	Sampled vertically into concrete curb along roadway, top of dam, 2-1/2 ft east of post No. 5 from west end. Partial bitumen coating on curb.	1/2 to 1 2 to 2-1/2 4 to 4-1/2 8 to 8-1/2	80 97 98 98
SB	Sampled vertically into roadway at top of dam, 150 ft east of right thrust block.	1/2 to 1 2 to 2-1/2 4 to 4-1/2 8 to 8-1/2 12 to 12-1/2	60 96 99 100 100
SC	Sampled vertically into roadway on top of dam, 400 ft from right thrust block.	1/2 to 1 2 to 2-1/2 4 to 4-1/2 8 to 8-1/2 16 to 16-1/2 24 to 24-1/2	73 98 99 98 100 99
SD	Sampled vertically into top of right thrust block, on roadway.	1/2 to 1 2 to 2-1/2 4 to 4-1/2 8 to 8-1/2 16 to 16-1/2 24 to 24-1/2	72 98 98 99 98 100

*Relative humidity referenced to 70 to 75°F.

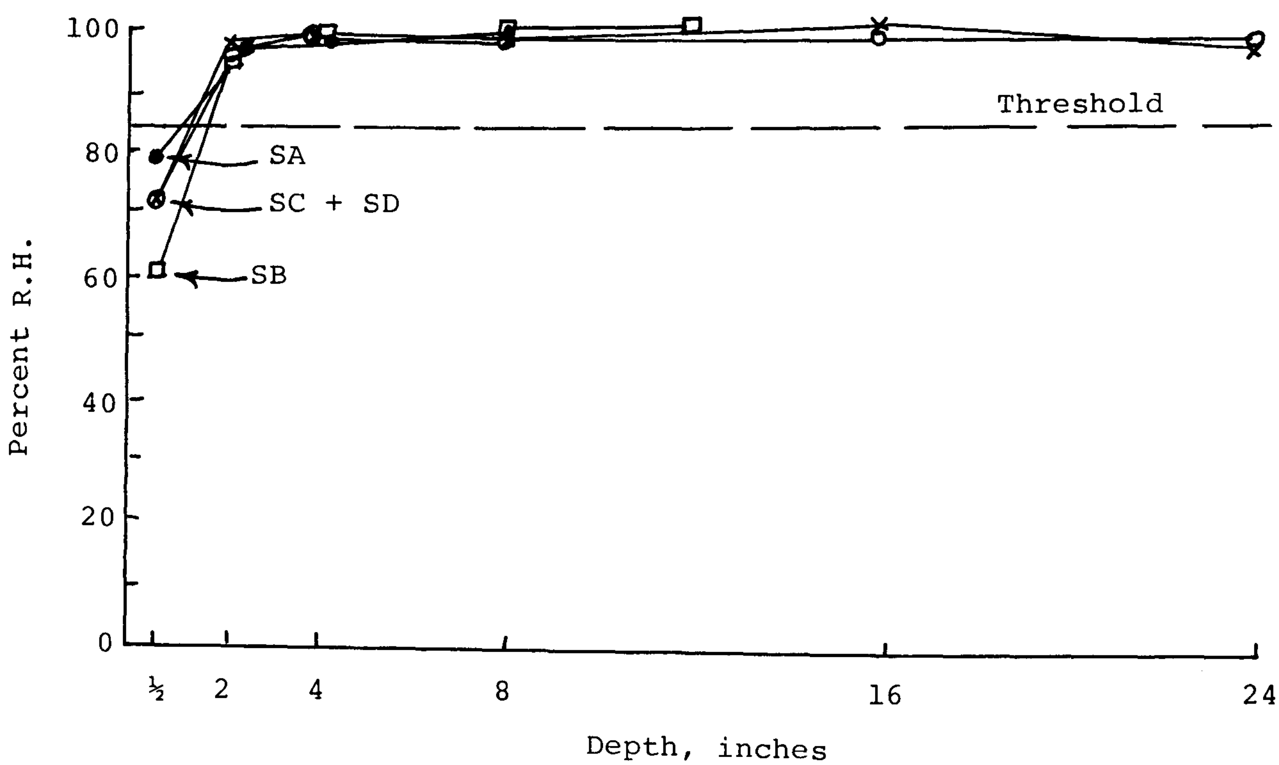

FIG. E1 - RELATIVE HUMIDITY DATA FOR STEWART MOUNTAIN DAM

SAMPLE	LOCATION	DEPTH IN.	R.H.* %
SE	Sampled horizontally into downstream face of dam, on powerhouse roof, 3-1/2 ft above roof.	1/2 to 1 2 to 2-1/2 4 to 4-1/2 8 to 8-1/2 16 to 16-1/2 24 to 24-1/2	25 39 39 64 94 98
SF	Sampled horizontally into downstream face of dam, over 54-in. penstock at landing on east side of powerhouse.	1/2 to 1 2 to 2-1/2 4 to 4-1/2 8 to 8-1/2 16 to 16-1/2 24 to 24-1/2	30 75 68 86 97 98
SG	Sampled horizontally into right thrust block, 17-1/2 ft from nose of block, 3-1/2 ft above roadway at ground level.	1/2 to 1 2 to 2-1/2 4 to 4-1/2 12 to 12-1/2 16 to 16-1/2 24 to 24-1/2	36 54 39 90 100 98

*Relative humidity referenced to 70 to 75°F.

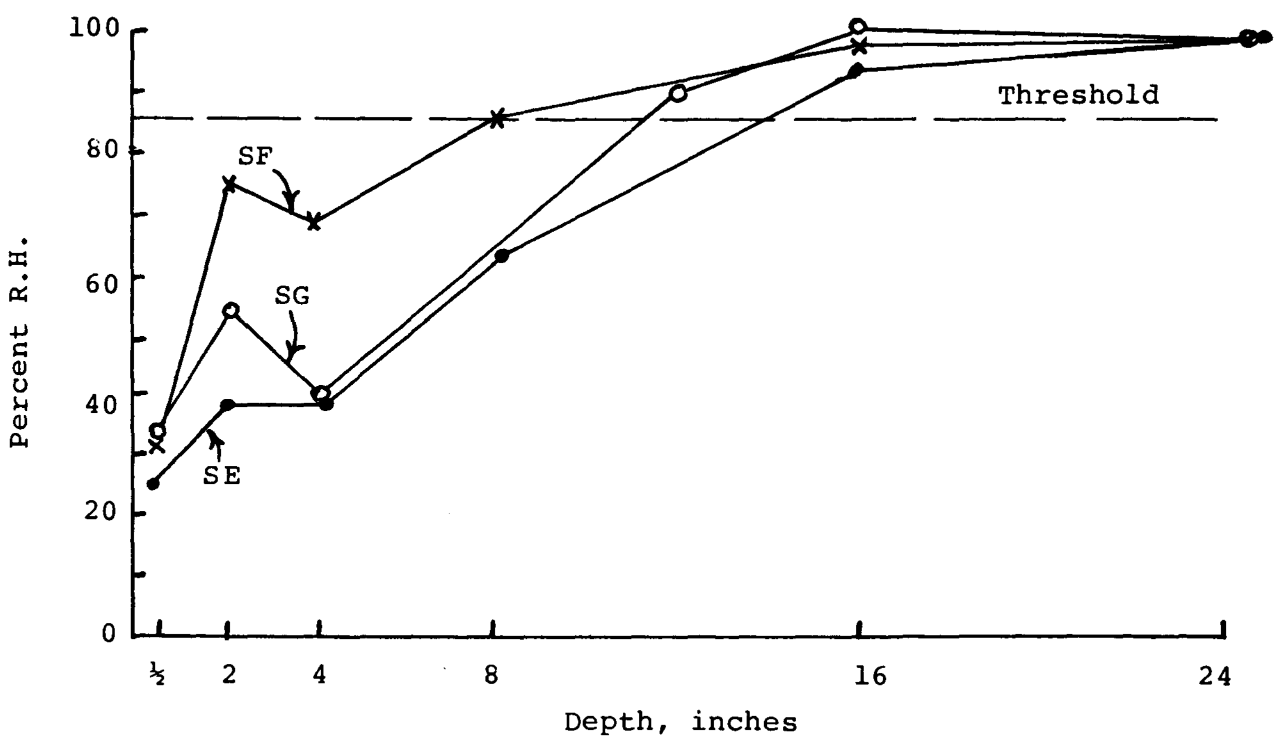

FIG. E2 - RELATIVE HUMIDITY DATA FOR STEWART MOUNTAIN DAM

FIGURE E3 - PETROGRAPHIC EXAMINATION OF CORES FROM STEWART MOUNTAIN DAM

Core No.	Core Location, Surface Condition of Concrete	Depth Examined in.	Observations
DH-SD	Vertical core on walkway-center of west thrust block. Concrete surface of walkway displays map-cracking.	8-17	Coarse aggregate was a natural gravel consisting of granite and quartzite in the 3/4 to 3-in. size range. Fine and coarse aggregate finer than 3/4 in. consisted primarily of granite, quartz and quartzite and feldspar, with lesser amounts of rhyolite, andesite and chert. Cryptocrystalline or glassy volcanic particles, 5/8-in. maximum size, displayed well-defined reaction rims and microcracks that contained alkali-silica gel. These cracks extended into surrounding mortar. The core also contained several prominent cracks, the origin of which could not be determined. They extended completely across the core, and through sockets formed by 1 to 3 in. aggregate particles. Copious amounts of partially carbonated alkali-silica gel were found in these sockets. However, there was no evidence that these particles had reacted. Ettringite and calcite, also are present. There was no evidence of other forms of progressive deterioration.
DH-SE	Horizontal core into south face of dam, 3-1/2 ft above powerhouse roof. Concrete surface is free of visible cracking.	21-33	Coarse aggregate consisted primarily of quartzite and granite with a 1-1/2-in. maximum particle size. One 4-in. size particle of reddish-purple andesite also was present. Fine aggregate consisted of similar rock types plus constituent minerals of these rock types. The large andesite particle is cryptocrystalline, and displays a pronounced reaction rim. Peripheral cracking occurs just inside the rim.

FIGURE E3 - PETROGRAPHIC EXAMINATION OF CORES FROM STEWART MOUNTAIN DAM (Continued)

Core No.	Core Location, Surface Condition of Concrete	Depth Examined in.	Observations
DH-SE	(continued)		Alkali-silica gel deposits are present on the particle surface and in the socket formed by the particle. Gel deposits are also present in entrapped air voids and in existing cracks immediately surrounding the particle. Smaller size volcanic particles also display reaction rims, microcracks extending into surrounding mortar, and gel deposits on fractured surfaces within the particles. One 3/4-in. quartzite particle also displays a well-defined reaction rim and gel on an internal microcrack. Ettringite and calcite are present as secondary reaction products. There was no evidence of other forms of progressive deterioration.
DH-SF	Horizontal core into south face of dam, east side of powerhouse, above 54 in. penstock. Concrete surface is free of visible cracking.	5-10	Coarse aggregate consists of andesite, rhyolite, granite, chert, and quartzite. Maximum particle size is 2 in. The fine aggregate contains the same rock types plus constituent minerals. A few microcracks extend across the core. Their origin could not be determined. A 2-in. andesite particle displays a dark reaction rim and internal microcracks filled with alkali-silica gel. Other smaller volcanic and chert particles display reaction rims and microcracks, some of which extend into surrounding mortar. Gel deposits are present in sockets of reacted aggregate particles. Ettringite and calcite are present in other aggregate sockets. There was no evidence of other forms of progressive deterioration.

FIGURE E3 - PETROGRAPHIC EXAMINATION OF CORES FROM STEWART MOUNTAIN DAM (Continued)

Core No.	Core Location, Surface Condition of Concrete	Depth Examined in.	Observations
DH-SG	Horizontal core into east face of thrust block, 3-1/2 ft above roadway, 17 ft from nose of block. Concrete surface is free of visible cracking.	13-18	This core section contains 3 to 4-in. particles of granite and rhyolite. Finer coarse aggregate particles, and the fine aggregate consist of granite, quartzite, chert, rhyolite, feldspar, and quartz. The large rhyolite particle displays a reaction rim but no microcracking. There is no alkali-silica gel associated with this particle. Smaller rhyolite and andesite and chert particles display reaction rims. Two andesite particles display peripheral cracking. One is associated with microcracks which extend outward from the particle in surrounding mortar. Relatively minor deposits of alkali-silica gel adhere to aggregate sockets and surfaces of smaller volcanic aggregate particles.

FIGURE E4 - LENGTH CHANGE OF STEWART MOUNTAIN DAM CORES IMMERSED IN WATER OR IN NaOH SOLUTION AT 100°F

Core No.	Core Length	Location	Depth in.	Test Sol'n	Percent Length Change									
					7D	14D	1 Mo.	2 Mo	3 Mo.	4 Mo.	5 Mo.	6 Mo.	7 Mo.	8 Mo.
SB-1	9 in.	Roadway, top of dam, 150 ft from right thrust block.	12-21	NaOH	.017	.013	.018	.017	.019	.018	.019	.013	.016	.016
SB-2	6 in.		5-11	H_2O	.018	.017	.018	.018	.020	.018	.013	.013	.013	.013
SC-1	9 in.	Roadway on top of dam, 400 ft from right thrust block.	13-22	NaOH	.017	.018	.018	.017	.019	.019	.020	.028	.032	.036
SD-1	6 in.	Roadway on right thrust block.	0-6	NaOH	.012	.010	.013	.015	.018	.023	.017	.027	.023	.024
SF-1	6 in.	Face of dam, on landing above 54-in. penstock.	3-9	H_2O	.065	.077	.100	.118	.125	.127	.125	.125	.127	.127
SF-2	9 in.		13-22	NaOH	.001	.017	.018	.023	.020	.034	.046	.067	.083	.092
SG-1	9 in.	Right thrust block 3-1/2 ft above roadway at ground level.	6-15	H_2O	.027	.027	.028	.030	.028	.029	.030	.027	.028	.028

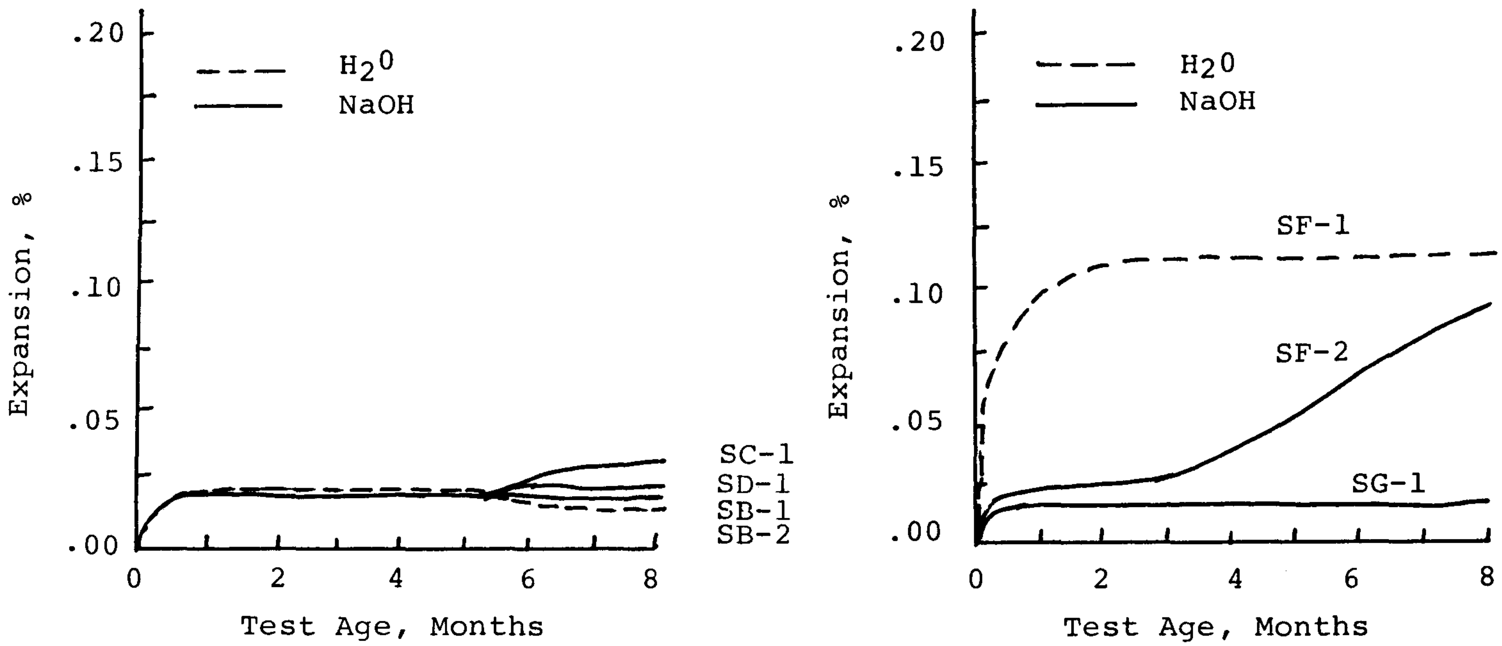

FIG. E5 - LENGTH CHANGES OF STEWART MOUNTAIN DAM CORES IMMERSED IN WATER OR 1N NaOH SOLUTION AT 100°F

NO.	LOCATION	DESCRIPTION	FLOW RATE, mm/DAY
SD-1	At 8-1/2 in. depth from exterior end of core DH-SD, taken on roadway on right thrust block.	Quartzite, 3 in. particle size. No evidence of reactivity.	0.3
SD-2	At 12-16 in. depth from exterior end of core DH-SD, taken on roadway on right thrust block.	Dense, reddish, brown granite, 3 in. particle size. No evidence of reactivity.	0.9
SE-1	At 26-30 in. depth from exterior end of core DH-SE, taken into face of dam, on powerhouse roof, 3-1/2 ft above roof.	Reddish-purple andesite, 4 in. particle. Reaction rims, some microcracking, minor gel reaction product.	10.2
SE-1	At 15-18 in. depth from exterior end of core, taken into right thrust block, 17-1/2 ft from nose of block, 3-1/2 ft above roadway at ground level.	Black rhyolite, 2-1/2" particle, contains reaction rim, but no interval microcracks or gel reaction product.	<0.0

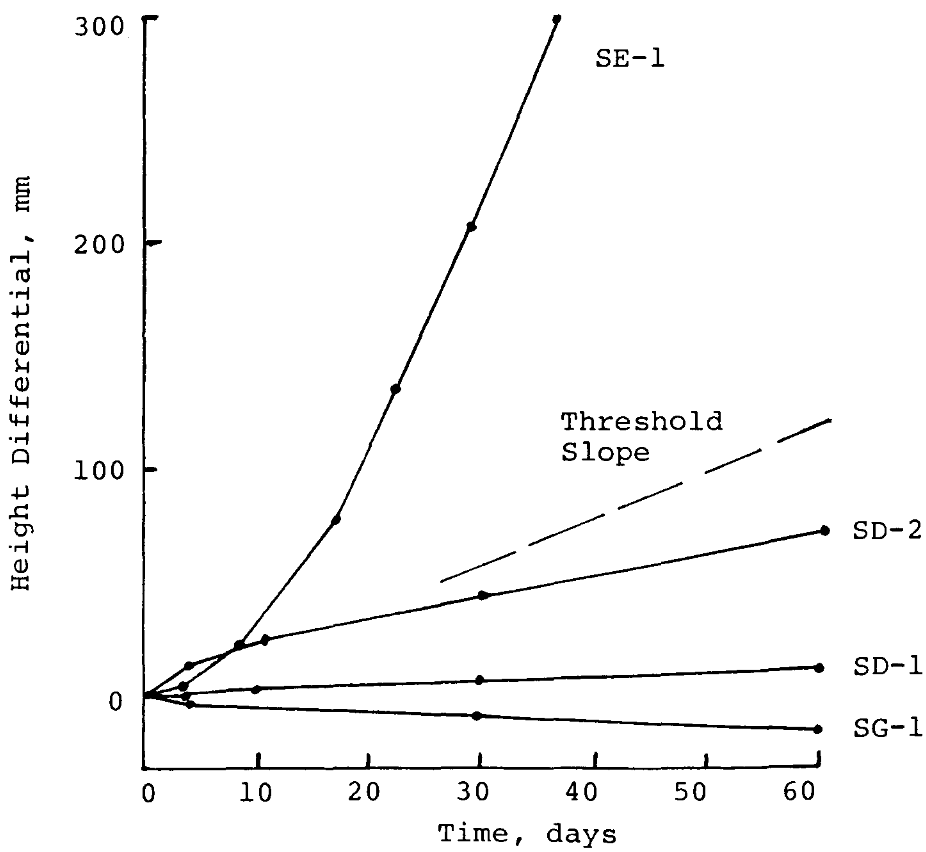

FIG. E6 - RESULTS OF OSMOTIC CELL TESTS FOR AGGREGATE FROM STEWART MOUNTAIN DAM

GPO 850-841

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.