REPORT

ON

THE CONDITION OF THE SUPERSTRUCTURE

OF

OLD CAVE CREEK DAM

FOR

MARICOPA COUNTY FLOOD CONTROL DISTRICT

April 1969

John Carollo Engineers

Phoenix Lafayette El Paso

FCD 69-1

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Reply to:
3308 NORTH THIRD STREET
PHOENIX, ARIZONA 85012
AREA CODE 602 265-4796

April 14, 1969

Flood Control District of
Maricopa County
3325 West Durango Street
Phoenix, Arizona 85009

Gentlemen:

Submitted herewith is our Report on Old Cave Creek Dam providing an engineering analysis of the present condition of the superstructure of the dam consisting of the walls and buttresses above the ground line.

This Report covers the testing laboratory work, a structural analysis of the dam superstructure, photographs of the dam showing the core locations, as well as a recommendation concerning the soundness of the dam superstructure.

At your convenience, we will be happy to discuss the contents of the Report in detail.

We wish to thank the staff of the Flood Control District of Maricopa County for the aid and cooperation given in the preparation of this Report.

Respectfully submitted,

JOHN CAROLLO ENGINEERS

Donald R. Preisler
Donald R. Preisler, Partner
Registration No. 2501

Bruce Wallace
Bruce Wallace, Engineer
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PLATES

Registered Professional Engineer Mechanical
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DONALD R. PREISLER
Date Signed 4/8/69
ARIZONA, U.S.A.

REPORT ON THE CONDITION OF THE SUPERSTRUCTURE OF OLD CAVE CREEK DAM

FOR

MARICOPA COUNTY FLOOD CONTROL DISTRICT

SCOPE

The purpose of this Report is to provide an engineering analysis of the present condition of the superstructure of Old Cave Creek Dam, located about six miles north of the City Limits of Phoenix (see Plates 1 and 2). The Report will present records of all field data collected, results of laboratory tests, engineering analysis of the dam, and recommendations as to the soundness of the dam. The scope of the work does not include and no investigations were made, into the substructure or foundation of the dam.

HISTORY OF THE DAM

Following a heavy rainstorm over the Cave Creek watershed in August 1921, the resulting runoff from the creek flooded a large area in west Phoenix and caused widespread damage. In addition to flood damage to homes and business places, the flood waters covered the first floor of the State Capitol Building. Immediate steps were taken to prevent a recurrence of the flood and later that year and in early 1922, plans were prepared for a concrete multiple arch dam to be constructed across Cave Creek in Section 3, Township 4 North, Range 3 East. Construction of the dam began in 1922 and it was completed in 1923. The State of Arizona, Maricopa County, City of Phoenix, Salt River Valley Water Users Association (now known as Salt River

Project), and the Paradise-Verde Irrigation District participated in the construction of the dam. At the present time, the dam is operated and maintained by the Salt River Project.

DESCRIPTION OF THE DAM

The dam consists of 38 reinforced concrete arches and supporting buttresses. The buttresses are spaced at 44-foot centers and with the dam abutments make the total length of dam 1692 feet. Plate 3 indicates a section of the dam at the highest buttress and Plate 4 indicates a plan view of the dam and its downstream elevation. At its deepest section, the crest of the dam is 60 feet above the creek bed and extends an additional 60 feet down through sand and gravel to a stratum of cemented gravel. The arches are 12 inches thick at the crest and are approximately 4 feet thick at the 120-foot depth. The top of the arches are capped with a horizontal 2-1/2 foot wide slab. A concrete wave cope, 2 feet high, extends above the cap slab. The arch barrels are nearly vertical at the crest of the dam and the slope becomes gradually flatter until the inclination of the barrels is 56 degrees with the horizontal at a depth of 80 feet below the crest. Below the 80-foot level the arch barrels are vertical.

The buttress walls are 12 inches thick at the crest and increase to a thickness of 8 to 10 feet at the 120-foot depth. The buttresses are "T" shaped with the flange on the downstream edge to provide additional stiffness to the member. The concrete mixture for the arches consisted of a 1:2:4 mix and a 1:2-1/2:5 mix was used for the buttresses. Reinforcing for the arches consisted of 3/4 inch square horizontal bars spaced at 2 feet on centers with 1/2 inch square bars vertical on 5-foot centers. The buttresses are reinforced with four 25-pound steel rails placed near the junction of buttresses with the arches.

HYDROLOGIC AND HYDRAULIC FEATURES

The Cave Creek drainage area above the dam consists of about 210 square miles of mountain and desert terrain. The dam creates a reservoir with a maximum size of 600 acres and has a capacity of about 14,000 acre-feet. During the August 1921 storm it was reported that 4 inches of rain fell on the Cave Creek watershed and the resulting runoff has been variously estimated at 20,000 cfs to 25,000 cfs. The dam was originally provided with three slide gates about 4 feet square. Two of these gate openings have been plugged and the present single ungated opening will pass approximately 7000 cfs at full pool elevation. To prevent overtopping of the structure during high flows, there is an emergency spillway located in a long natural saddle about one mile east of the dam (see Plate 2). The elevation of the top of the dam is 1640 feet and the saddle elevation averages about 1637.5 feet. It is not known if the emergency spillway has spilled any water from the reservoir. Any water passing the emergency spillway would return to Cave Creek at a point about a mile and a half downstream from the dam.

PRESENT CONDITION OF THE DAM

The visible portion of the dam above the valley floor appears to be in excellent condition after 47 years in place. Numerous cracks were noted in the downstream face of the arch, however, cracks in a concrete structure are not always an indication of structural failure. Horizontal cracks can be seen along many of the cold or construction joints in all the arches. These horizontal cracks were noted usually between the 16 to 48-foot levels below the crest. No horizontal cracks were noted on the upstream side of the arches. The absence of visible evidence of upstream cracks is probably due to the small size of the cracks on the upstream side and to probable filling of the crack space with mud and silt deposits. The horizontal cracks in the downstream face appear to be more open at a point about 30 to 40 feet down from the crest. Vertical cracks were noted near the midpoint of the downstream side of several arches. These vertical cracks were not lengthy and usually extended from 20 feet down from the crest to the 40-foot level. The vertical cracks were not noted on the upstream side of the arches.

Each buttress has one or more horizontal cracks following cold or construction joints. In addition, nearly all the buttresses have a vertical crack at about the midpoint of the buttress. The horizontal and vertical cracks in the buttress extend all the way through the concrete. The vertical cracks in the buttresses are probably caused by contraction.

Brown colored stains on the concrete below horizontal cracks are evident on the downstream side of most arches in the central or deepest portion of the dam. These stains are more marked at the 30 to 40-foot level below the crest and are usually heaviest at the sides of the arch near the buttress. The stains indicate a water leakage through the dam probably when the flood pool is near the top of the dam. The brown color of the stains could be caused by rusting of the reinforcing steel or a leaching of color from soil carried by the impounded water. It is believed that the latter is the reason for the discoloration since reinforcing steel cut by cores at the cracks did not reveal any indication of pitting or rusting of the steel. Calcium effervescence is also common, primarily at the lower horizontal cracks and at some tie wire locations.

The outlet through the dam is in good condition except where the trash rack steel bars connected to the structure. Here the concrete at the upper end of the bars has broken away from the main structure. No extensive erosion was noted in the cemented gravel downstream from the concrete outlet channel.

Siltation behind the dam appears to be slight and little build-up of silt was noted against the upstream side of the dam. From sighting across the top of the dam, there appears to be no vertical or horizontal displacement of the structure.

LABORATORY TESTS

In January 1969, Engineering Testing Laboratories, Inc., of Phoenix took twelve 4-inch cores and four 6-inch cores in the downstream face of the dam. Plate 4 indicates the approximate location of the cores. The 4-inch cores were taken at horizontal crack locations while the 6-inch cores were obtained in sound concrete for a determination of the present strength of the concrete. Since the horizontal cracks along the construction joints are in a more or less horizontal plane through the dam and the face of the dam is not a vertical plane and the cores had to be drilled perpendicular to the face, the core drilling had to be started at a lower elevation than the face of the crack in order to intersect the crack somewhere within the concrete. Therefore, no cores were able to follow a crack for its full width through the dam. One core (Core No. 5) indicated that the crack extended completely through the dam.

This core went completely through the dam at a point 16'-3" down from the top. All later cores were limited to a 12-inch depth and can not be used as an indication of the total depth of a crack. Several cores indicated that the cracks stopped at depths ranging from 3-1/2 inches to 5-1/2 inches while other cracks were noted at the interior end of the 12-inch depth of the core and evidently continue deeper into the wall. No cores were taken in the buttresses.

Tests were made on the four 6-inch cores with the resulting following compressive strengths:

Core No. 2	3842 psi
Core No. 6	3103 psi
Core No. 10	2933 psi
Core No. 15	4061 psi

These results indicate that the concrete is excellent quality, especially considering the concrete mixing and placing methods used in 1922. The twelve 4-inch cores drilled to follow cracks indicated the concrete to be dense and of good quality. In only one 4-inch core were there indications of small voids in the concrete.

Photographs indicating the location of corings and individual cores are found on Pages P-1 through P-9 of this Report. For a more complete description of the cores, methods of obtaining the cores, and laboratory results, see the report of Engineers Testing Laboratories, Inc., contained in Appendix A of this Report.

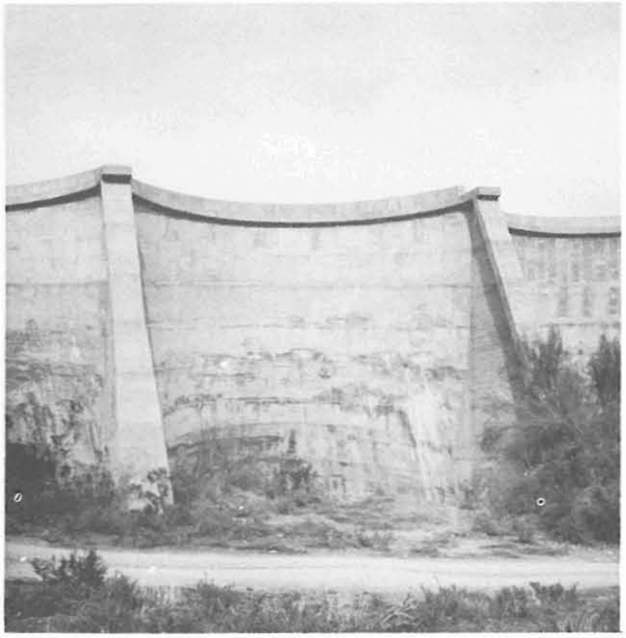
STRUCTURAL ANALYSIS

The arches and buttresses were analyzed at several elevations to determine the structural soundness of the dam. The arches at 15, 25, 35, and 45 feet below the crest were analyzed and the maximum stress found was 479 psi which does not include temperature stress. Thus, it appears that the arches in themselves are structurally sound. The buttresses were analyzed first for bending and then for shear. Tension in the upstream face of the arches exceeds the allowable stresses when considered as a monolith with the buttresses, however, considering the buttresses by themselves gives satisfactory stresses in bending. Under load the horizontal cold joints in the arches would tend to open up and relieve the tension in the arches. The resistance of the buttresses to shear and sliding is much lower than is recommended at the present time for new dams. Safety factors as low as 1.03 were found for a water level at Elevation 1642.0 whereas a minimum safety factor of 4.0 or 5.0 is presently being recommended by various agencies. A structural analysis of the superstructure of the dam is contained in Appendix B of this Report.

CONCLUSIONS AND RECOMMENDATIONS

As a result of our investigations and in view of the fact that the dam has withstood the loads imposed upon it for the past 47 years, we have concluded that the dam superstructure is sound provided that the loads on the dam are not increased in any manner. We, therefore, recommend that care be taken to insure that the natural emergency spillway elevation of 1637.5 not be raised and that the existing width of this spillway not be decreased. Repairs should be made on the existing trash rack where it has pulled away from the structure.

PHOTOGRAPHS

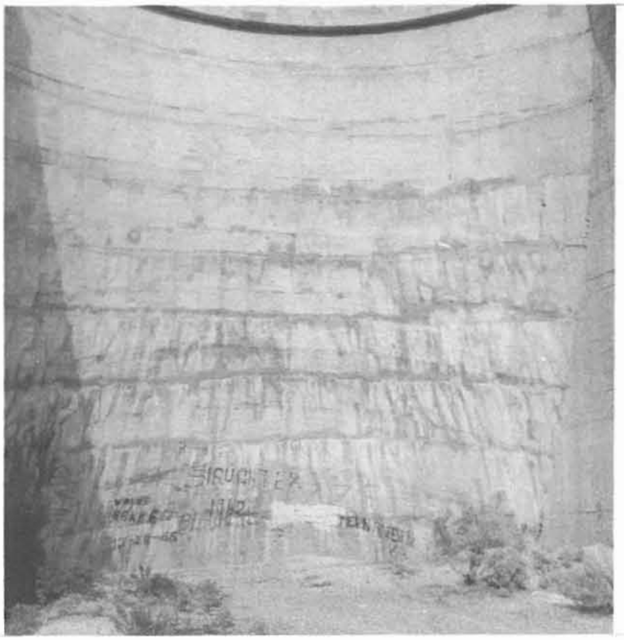


4" Core No. 1
Arch No. 6

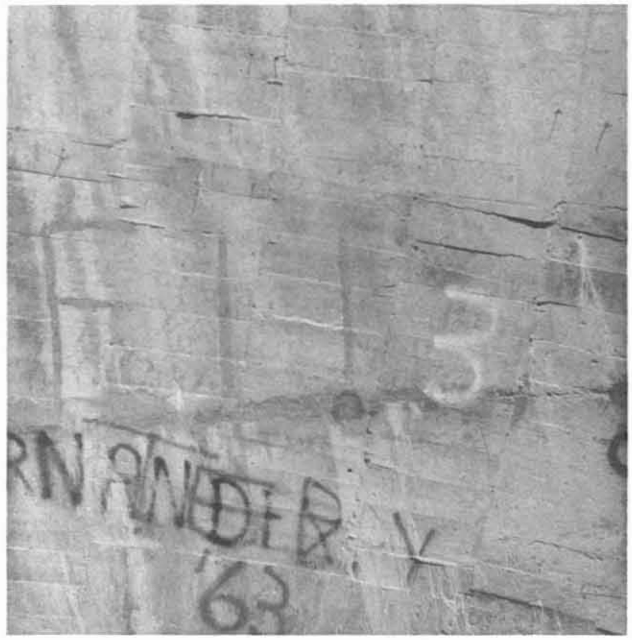
4" Core No. 1
Arch No. 6

4" Core No. 2
Arch No. 8

6" Core No. 2
Arch No. 8

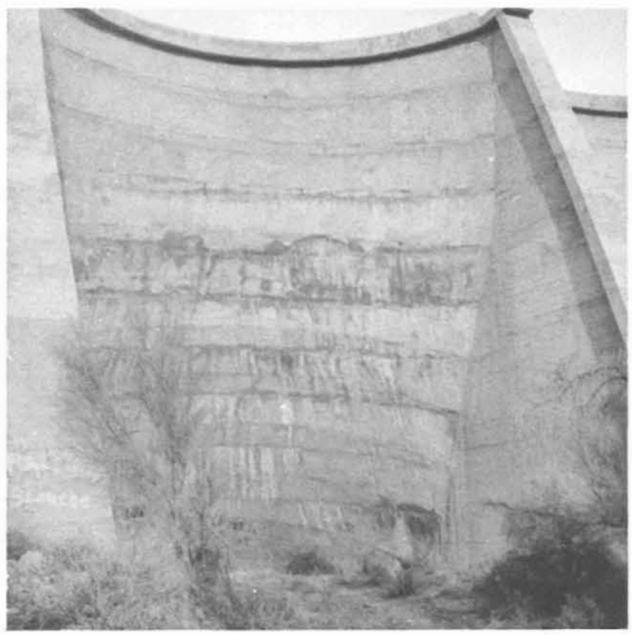


4" Core No. 3
Arch No. 10

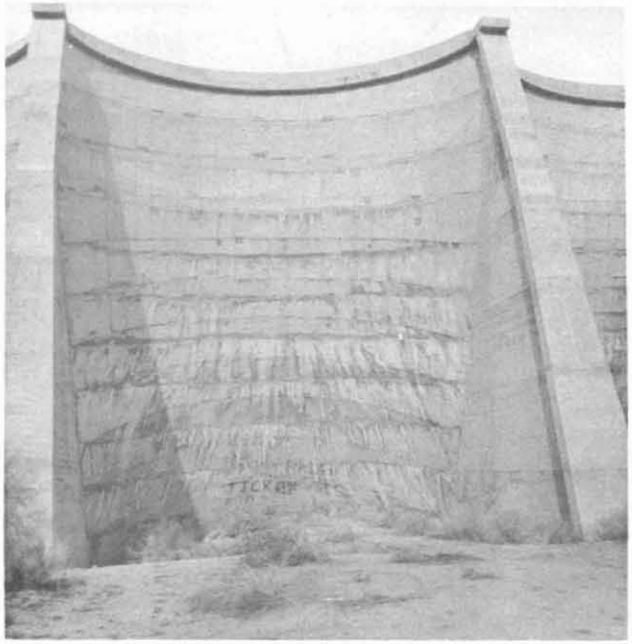


4" Core No. 3
Arch No. 10

4" Core No. 4
Arch No. 11

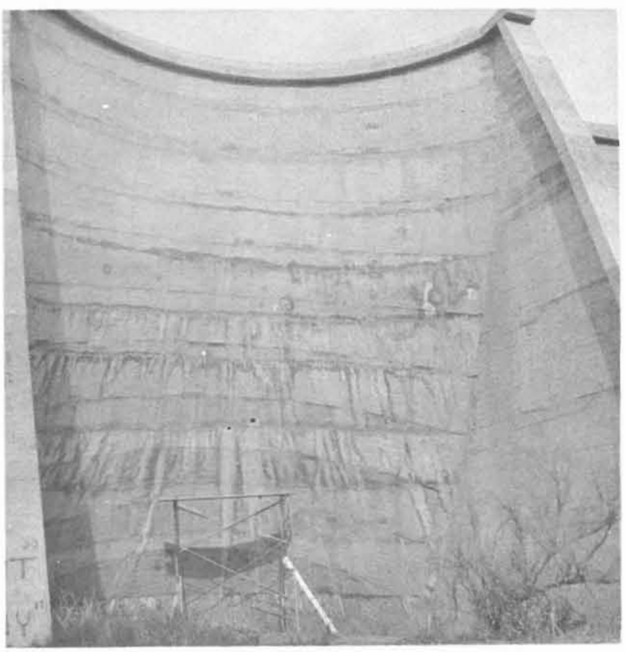


4" Core No. 4
Arch No. 11

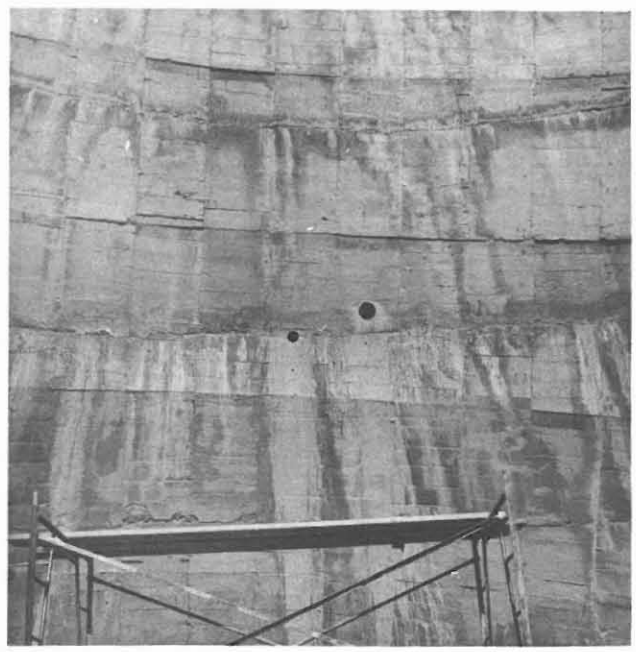


4" Core No. 8
Arch No. 18

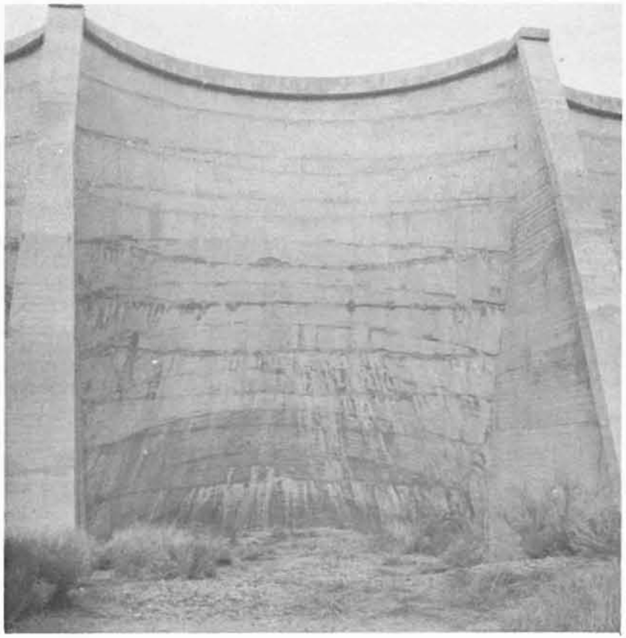
4" Core No. 8
Arch No. 18



4" Core No. 9
6" Core No. 10
Arch No. 22

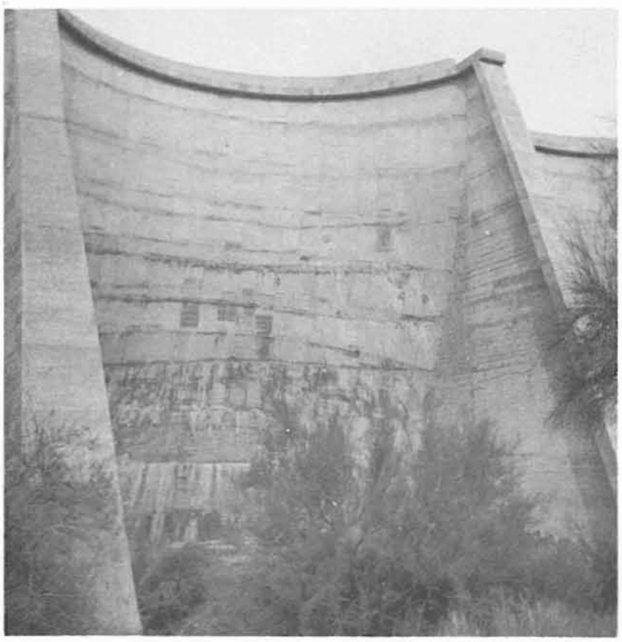


4" Core No. 9
6" Core No. 10
Arch No. 22



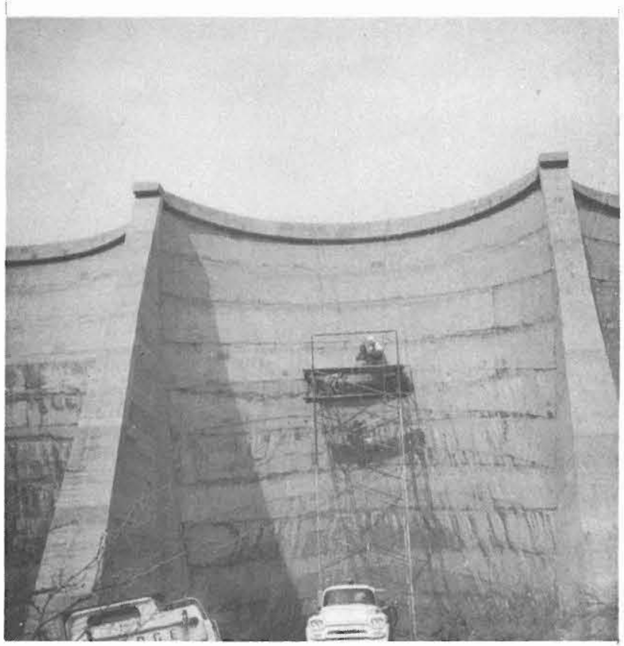
4" Core No. 12
Arch No. 27

4" Core No. 12
Arch No. 27
Note: Holes from rifle bullets

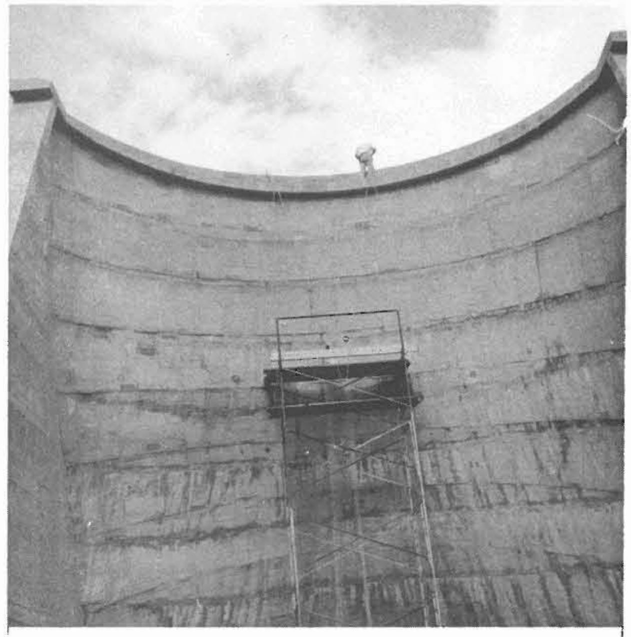


4" Core No. 13
Arch No. 29

4" Core No. 13
Arch No. 29

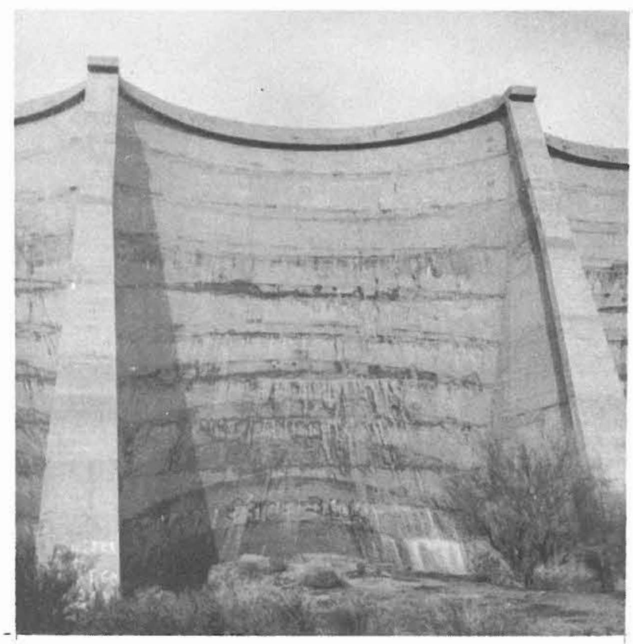


4" Core No. 5
6" Core No. 6
Arch No. 13

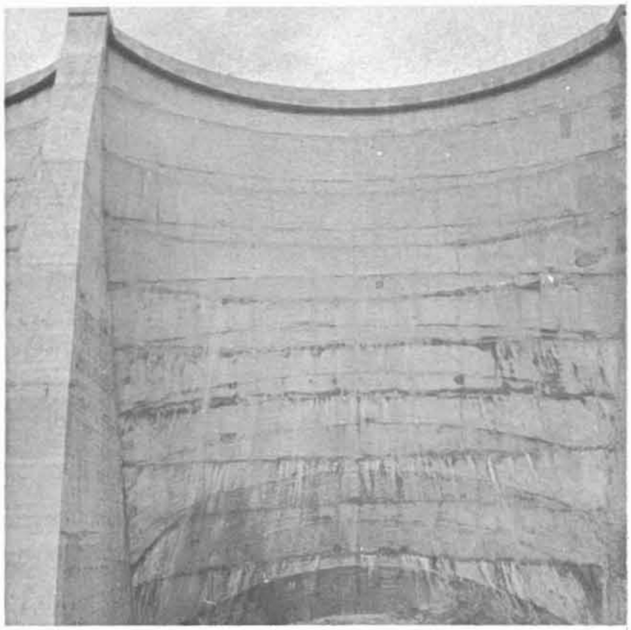


6" Core No. 6
4" Core No. 5
Arch No. 13

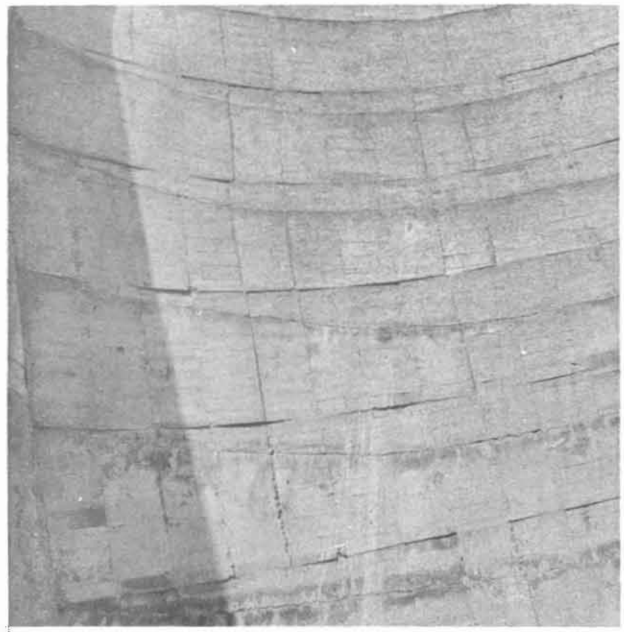
4" Core No. 7
Arch No. 16



4" Core No. 7
Arch No. 16

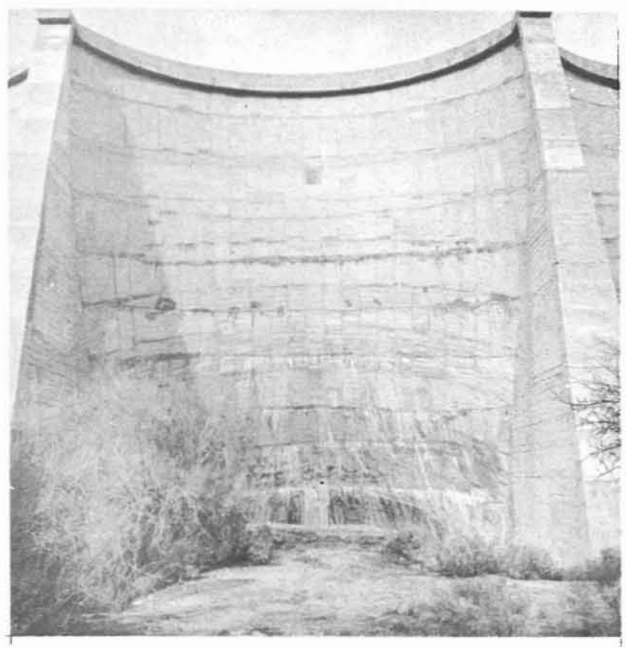


4" Core No. 11
Arch No. 25

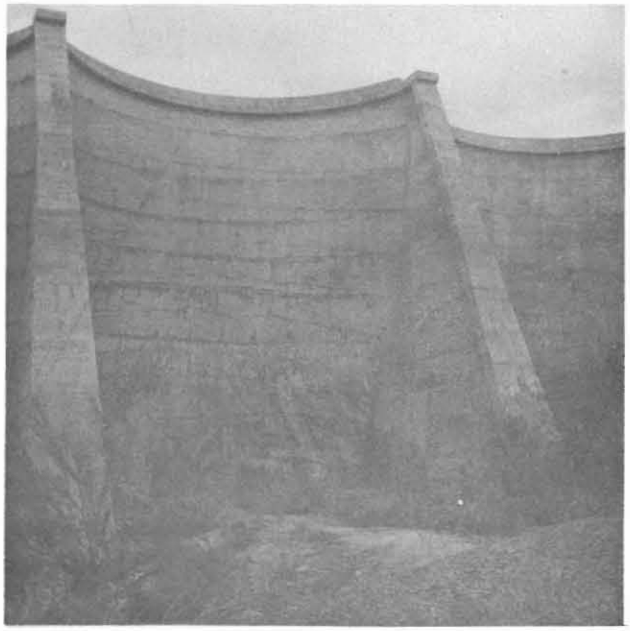


4" Core No. 11
Arch No. 25

6" Core No. 15
Arch No. 33
4" Core No. 14



6" Core No. 15
4" Core No. 14
Arch No. 33

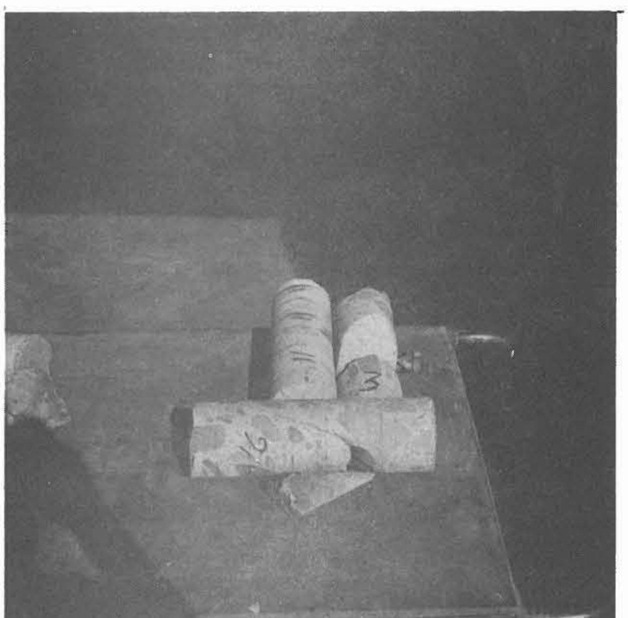


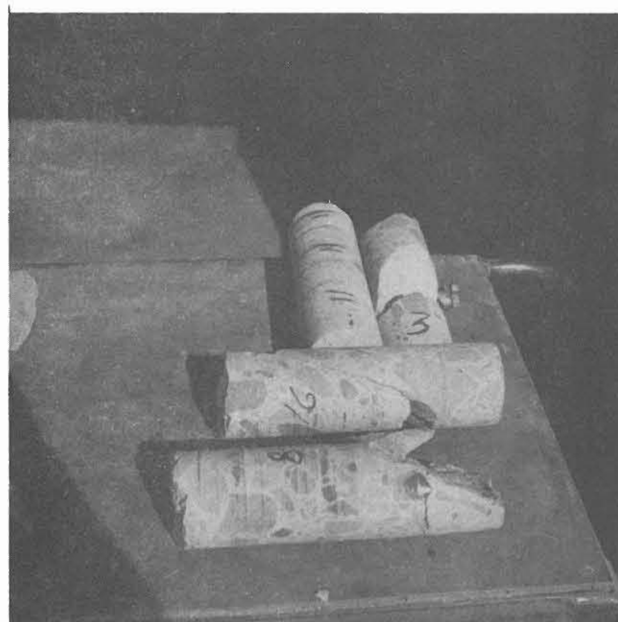
4" Core No. 16
Arch No. 36

4" Core No. 16
Arch No. 36

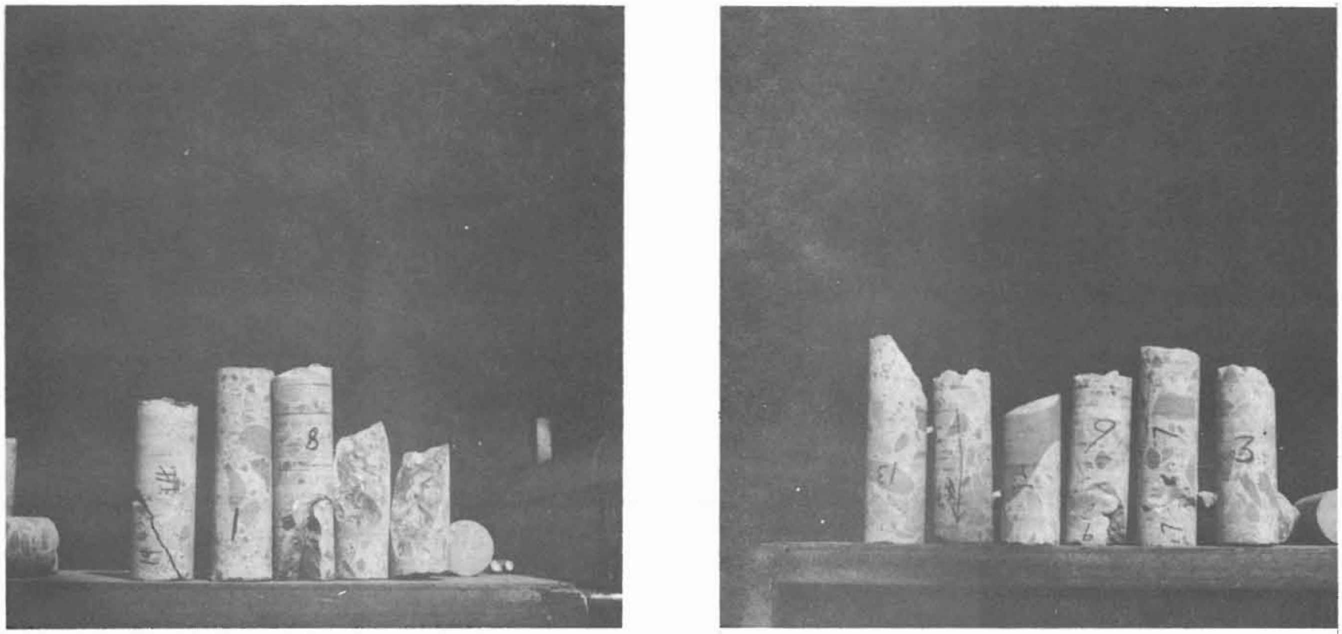
Concrete Cores

CONCRETE CORES

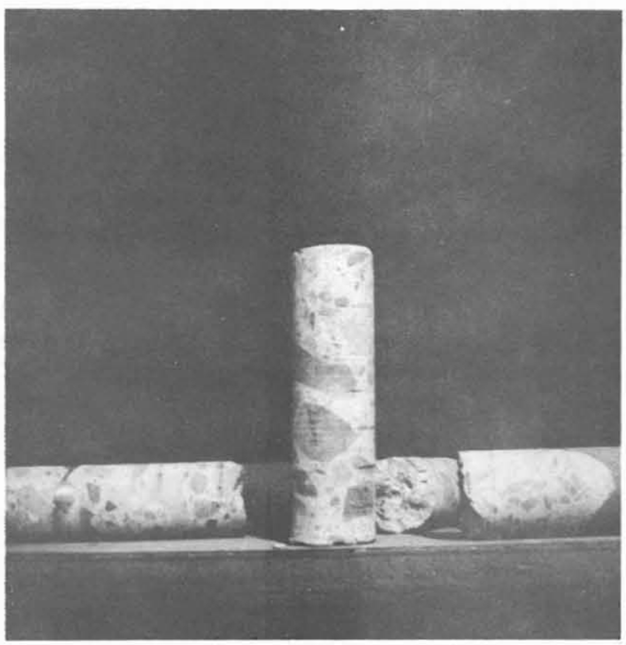




CONCRETE CORES

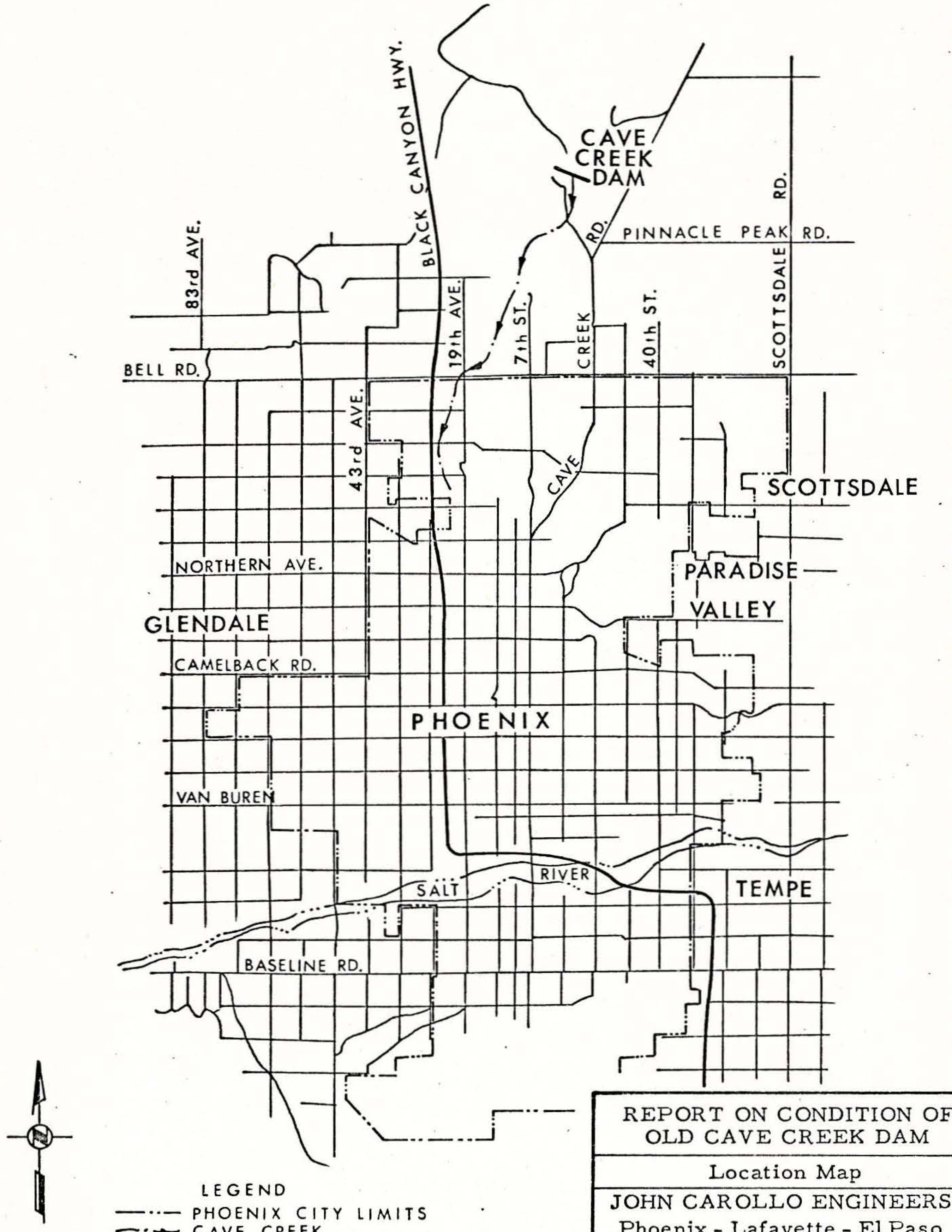


CONCRETE CORES



CONCRETE CORES

PLATES

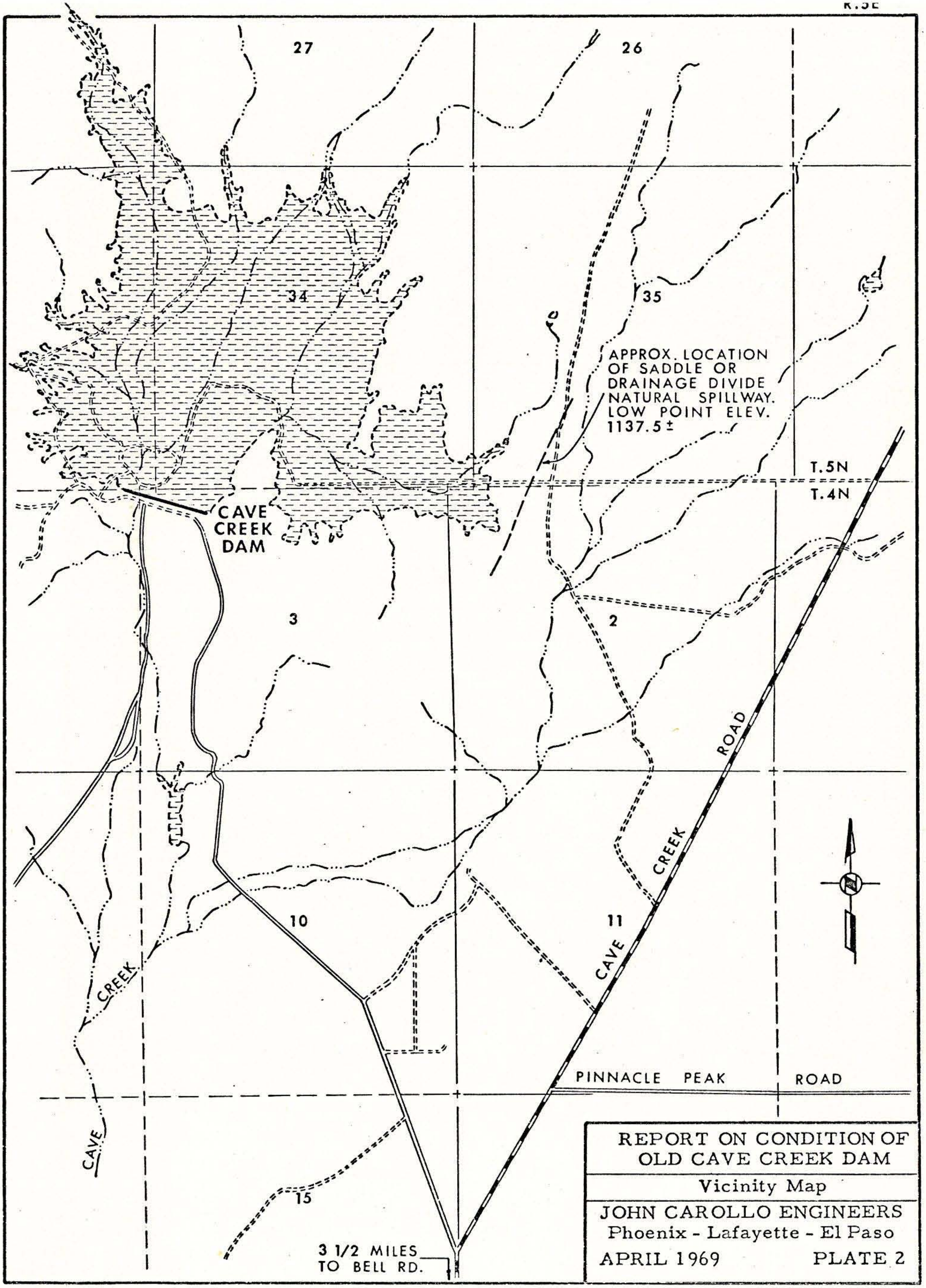


REPORT ON CONDITION OF OLD CAVE CREEK DAM

Location Map

JOHN CAROLLO ENGINEERS
Phoenix - Lafayette - El Paso

APRIL 1969 PLATE 1

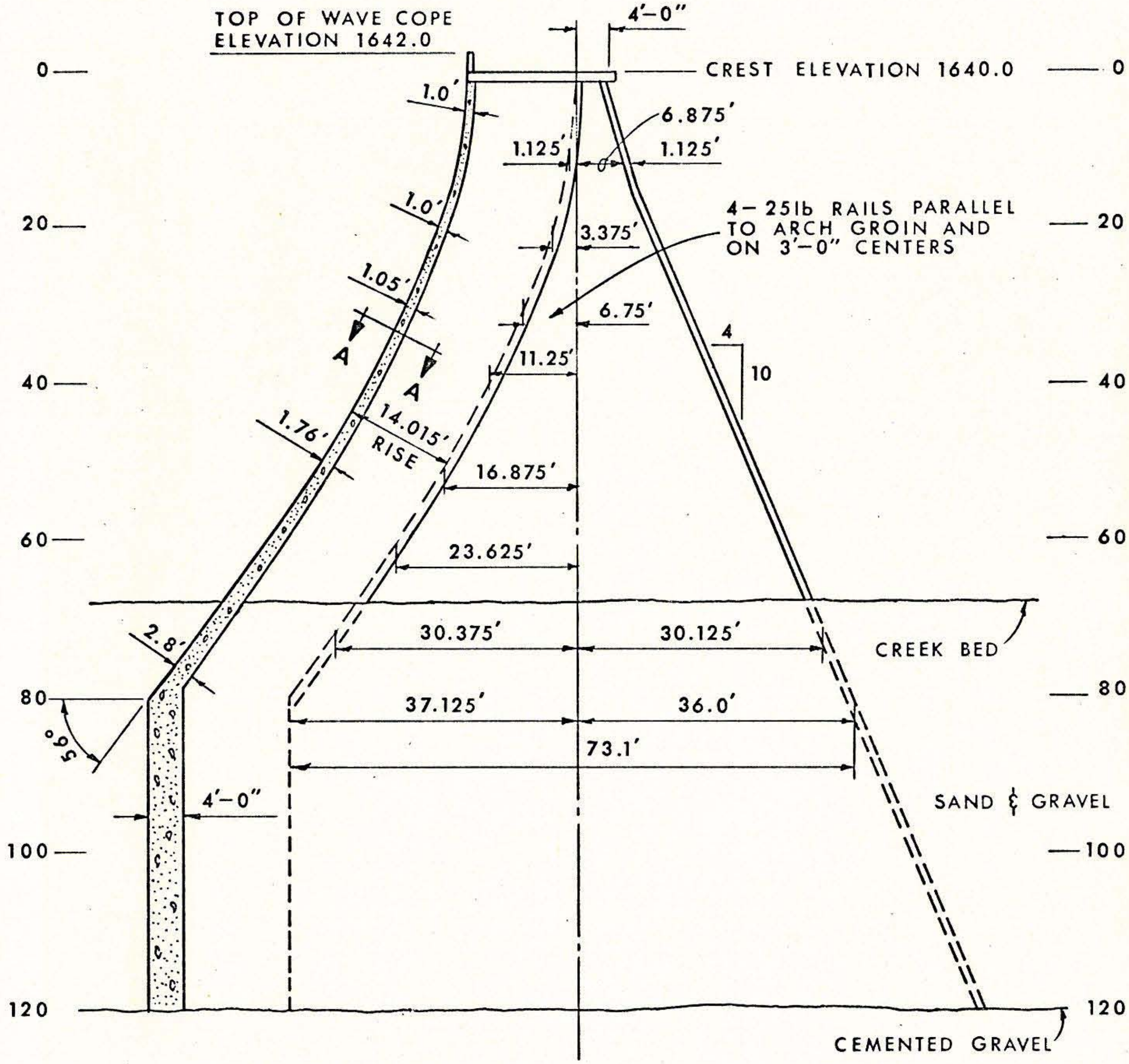


REPORT ON CONDITION OF OLD CAVE CREEK DAM

Vicinity Map

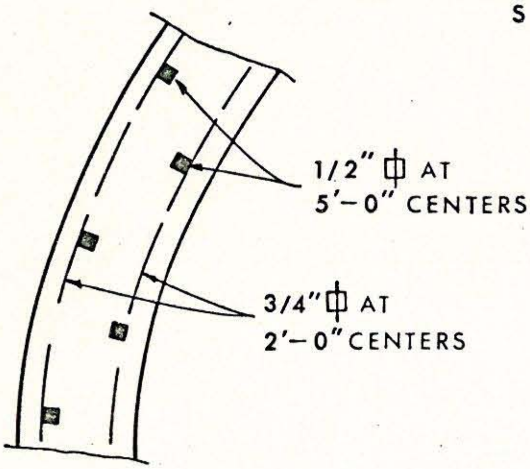
JOHN CAROLLO ENGINEERS
Phoenix - Lafayette - El Paso

APRIL 1969 PLATE 2



SIDE ELEVATION AT HIGHEST BUTTRESS

SCALE 1"= 20'



SECTION A–A

REPORT ON CONDITION OF OLD CAVE CREEK DAM
Section of the Dam
JOHN CAROLLO ENGINEERS Phoenix - Lafayette - El Paso
APRIL 1969 PLATE 3

DOWNSTREAM ELEVATION

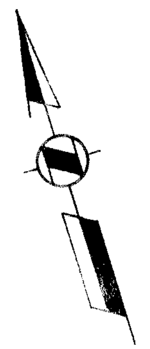
SCALE 1"=50'

LEGEND

o CORE TAKEN IN CONCRETE
CORE No's. 2, 6, 10, & 15 - 6" CORES
ALL OTHERS - 4" CORES

PLAN

SCALE 1"=50'



JOHN CAROLLO ENGINEERS

PHOENIX — LAFAYETTE — EL PASO

REPORT ON CONDITION OF
OLD CAVE CREEK DAM

Plan and Elevation
of the Dam

APRIL 1969 PLATE 4

APPENDIX A

TESTING LABORATORY REPORT

ETL

Engineers Testing Laboratories, Inc.

J. E. WARNE, JR., P.E.
TOM W. THOMAS, P.E.
H. LEE MYERS, P.E.

2525 E. Indian School Rd. - 264-4781 - Phoenix, Arizona 85016
428 South Olsen - 622-3663 - Tucson, Arizona 85719

JOHN CAROLLO ENGINEERS
3308 NORTH THIRD STREET
PHOENIX, ARIZONA

26 FEBRUARY 1969

ATTENTION: DONALD R. PREISLER

RE: CAVE CREEK DAM JOB NO. 69-36

IN ACCORDANCE WITH YOUR REQUEST, WE HAVE TAKEN TWELVE 4" CORES AND FOUR 6" CORES ON THE DOWNSTREAM FACE OF CAVE CREEK DAM. CORES WERE TAKEN AT LOCATIONS DESIGNATED IN YOUR LETTER OF 25 NOVEMBER 1968, TO THE MARICOPA COUNTY FLOOD CONTROL DISTRICT. DIRECTIONS STATED THAT THE 4" CORES WOULD BE TAKEN TO WITHIN 12" OF THE UPSTREAM FACE OF THE DAM, AND 6" CORES TO BE NOT LESS THAN 12" DEEP. NO. 3 CORE WAS TAKEN FIRST AND WAS CORED COMPLETELY THROUGH THE DAM (18½" LONG). THE LENGTH OF THE CORE CHECKS WITH THE DAM THICKNESS FOR THIS ELEVATION SHOWN ON SHEET A23-5 OF THE PLANS FOR CAVE CREEK DAM, WHILE CORES TAKEN AT DIFFERENT ELEVATIONS CORRESPONDED GENERALLY WITH THICKNESSES SHOWN ON THE PLANS. AFTER DISCUSSION WITH MR. PREISLER IT WAS DECIDED TO TAKE ALL CORES TO 12" IN DEPTH REGARDLESS OF LOCATION.

ALL 4" CORES WERE TAKEN AT CRACK LOCATIONS IN AN ATTEMPT TO DETERMINE THE DEPTH OF CRACKS AND THE CONDITION OF THE REINFORCING STEEL.

ALL 6" CORES WERE TAKEN IN SOUND AREAS TO DETERMINE THE STRENGTH OF THE CONCRETE. DATA FOR EACH CORE IS AS FOLLOWS:

JOHN CAROLLO ENGINEERS
CAVE CREEK DAM
JOB NO. 69-36

CORE NO. 1 - ARCH NO. 6: 4" DIAMETER, 12½" LONG. CORED IN CRACK, 20' DOWN FROM DAM TOP AND 5'6" FROM EAST ABUTMENT. THE CRACK WAS SMALL, EXTENDING TO A DEPTH OF 3½". CORE WENT COMPLETELY THROUGH DAM AND INDICATED GOOD DENSE CONCRETE THROUGHOUT.

CORE NO. 2 - ARCH NO. 8: 6" DIAMETER, 12" LONG. CORED BETWEEN JOINTS ONE AND TWO, DOWN 33' FROM DAM TOP AND 15'4" FROM EAST ABUTMENT. THIS CORE WAS TAKEN FOR TEST PURPOSES AND RESULTED IN A COMPRESSIVE STRENGTH OF 3842 PSI.

CORE NO. 3 - ARCH NO. 10: 4" DIAMETER, 18½" LONG. CORED IN PATCHED CRACK, DOWN 39'7" FROM DAM TOP AND 7' FROM EAST ABUTMENT. CORE WENT COMPLETELY THROUGH DAM, AND BROKE AT A DEPTH OF APPROXIMATELY 8" DUE TO POOR BOND WITH SOME FLAT AGGREGATE, OTHERWISE THE CONCRETE APPEARED TO BE OF GOOD QUALITY.

CORE NO. 4 - ARCH NO. 11: 4" DIAMETER, 19½" LONG. CORED BELOW CRACK IN AREA COVERED WITH BROWN MUD STAINS, DOWN 45'3" FROM DAM TOP AND 2'6" FROM EAST ABUTMENT. CORE WENT COMPLETELY THROUGH DAM, WAS STARTED BELOW A CRACK IN AN EFFORT TO INTERSECT SAME. HOWEVER, THE CRACK WAS NEVER INTERSECTED. GOOD DENSE CONCRETE EXCEPT FOR A DEPTH OF FROM 10" TO 16" WHERE SMALL VOIDS WERE NOTICED AROUND AGGREGATE ON ONE SIDE.

CORE NO. 5 - ARCH NO. 13: 4" DIAMETER, 12¾" LONG. CORED IN MUD STAINED AREA, 16'3" DOWN FROM DAM TOP AND 21'6" FROM EAST ABUTMENT. CORE WENT COMPLETELY THROUGH DAM. STARTED CORING BELOW A CRACK AND ENCOUNTERED SAME AT A DEPTH OF 2" IN. THE CRACK EXTENDED COMPLETELY THROUGH DAM, WITH THE BROWN STAIN NOTICEABLE THROUGHOUT. CUT THROUGH ¾" REINFORCING BAR AT 9½" DEPTH, ONE FACE OF WHICH WAS EXPOSED IN THE CRACK. THIS FACE WAS SLIGHTLY RUSTY WITH NO PITTING EVIDENT. CONCRETE APPEARED TO BE GOOD, DENSE CONCRETE.

Core No. 6 - Arch No. 13: 6" diameter, 12" long. Cored in same area as No. 5, 15'6" down from dam top and 20'3" from east abutment. This core was taken for test purposes and resulted in a compressive strength of 3103 psi.

Core No. 7 - Arch No. 16: 4" diameter, 12" long. Cored in crack 43'7" down from dam top and 25' from east abutment. Crack extended to a depth of 4½". Cut through ¾" reinforcing bar 3¼" in. No rust on bar and concrete appeared to be good and dense throughout.

Core No. 8 - Arch No. 18: 4" diameter, 12½" long. Cored in crack, heavy brown stain along with heavy effervescence, 48'5" down from dam top and 6'4" from east abutment. Crack extended to a depth of 5½". Cut through ¾" reinforcing bar 3½" in. No rust on bar and concrete appeared to be good and dense throughout.

Core No. 9 - Arch No. 22: 4" diameter, 12" long. Cored in crack, heavy effervescence, 34' down from dam top and 17' from east abutment. Crack extended to a depth of 3½". Core broke off at end due to concentration of aggregate. Otherwise, concrete appeared to be good and dense throughout.

Core No. 10 - Arch No. 22: 6" diameter, 12" long. Cored 34'9" down from dam top and 18'6" from east abutment. This core was taken for test purposes and resulted in a compressive strength of 2933 psi.

Core No. 11 - Arch No. 25: 4" diameter, 12" long. Cored in crack 21' down from dam top and 34'8" from east abutment. Started below crack and encountered crack at a depth of 5". Crack was in the approximate center at the end of the core. Concrete appeared to be good and dense throughout.

Core No. 12 - Arch No. 27: 4" diameter, 16" long. Cored in crack, heavy effervescence in this area, 43' down from dam top and 22'10" from east abutment. Cut through $\frac{3}{4}$" reinforcing bar $2\frac{3}{4}$" in. Bar showed no rust, but concrete area showed a small crack from face of bar to the face of the dam. Core broke at depths including locations at rebar on end (16") and at 8" in where a large rock was but, $6\frac{1}{2}$" of which was in the core. Rock was bonded well to the other section of the core. With the exception of the crack and rock, the concrete appeared to be good and dense.

Core No. 13 - Arch No. 29: 4" diameter, $12\frac{1}{2}$" long. Cored in crack, heavy brown stain area, 44' down from dam top and 17'6" from east abutment. Started coring below crack, encountered crack at a depth of $8\frac{1}{2}$" and core broke as crack angled across it. Concrete appeared to be good and dense with the exception of small check cracks in area 3" to 6" in on the core.

Core No. 14 - Arch No. 33: 4" core, $10\frac{1}{2}$" long. Cored in crack where concrete surface was covered with a brown stain and heavy effervescence, 42'3" down from dam top and 28'6" in from east abutment. Crack extended to a depth of $5\frac{1}{2}$". Cored 12" but core broke at $10\frac{1}{2}$" due to large flat rock. Concrete appeared to be good and dense.

Core No. 15 - Arch No. 33: 6" diameter, 12" long. Cored in same area as No. 14, 42'10" down from dam top and 19'6" in from east abutment. This core was taken for test purposes and resulted in a compressive strength of 4061 psi.

Core No. 16 - Arch No. 36: 4" diameter, 12" long. Cored in crack and spalled area, 44'4" down from dam top and 7'3" from east abutment. Started coring below crack and encountered crack 3" to 11" continuously from depth where it emanated away from core area. Crack was covered throughout with a heavy brown stain. Concrete appeared good and dense throughout.

Pictures showing areas where cores were taken are enclosed. Closeups were taken to show cored areas and others were taken to show the general condition of the concrete in the entire arch sections.

Cores taken show that pour, or cold joints, extend through the dam. This condition accounts for the general appearance of the downstream dam face. Brown stains which possibly could be caused by reinforcing steel rusting, are more probably caused by leaching of rocks or soil, native to the area. Since the dam was built for flood control purposes, the storage area above the dam is normally dry and the reinforcing bars which may be exposed in the joint areas are not subject to rust as was shown in reinforcing bars cut in these areas. Mud stains are evident below almost each joint in the dam face and deposits are heavier at lower elevations. Calcium effervescence is also common, primarily at the lower joints, probably due to increased presence of water and also subjected to greater hydrostatic pressure.

General appearance of the dam shows the concrete to be in excellent shape, partly due to weather conditions in the Phoenix area, and in view of the dam being 45 years old, cores and tests taken show the concrete to be of excellent quality.

The 6" concrete cores tested give a low compressive strength of 2993 psi and a high of 4061 psi which further indicates that the concrete is of excellent quality, especially considering the concrete mixing and placing methods used in 1922.

John Carollo Engineers
Cave Creek Dam
Job No. 69-36

Pictures of the cores are enclosed. All diagonal cracks are due to drilling through the cold or pour joints. It was difficult to follow the cracks through the dam, since the dam face is curved, both vertically and horizontally. The drill was fastened to the dam face, so the core was drilled normal to the surface, while the cold or pour joint was formed in a horizontal plane. By starting the core drill below the crack, the crack was encountered at different distances in from the dam face and as has been stated, some of the cores showed the joint completely through the dam.

The largest rock encountered is seen in core No. 8. Evidently native rock from the area was used as aggregate and in general it consists of good dense rock.

This report, with descriptions of tests made, is submitted to your firm for your information and conclusions.

ENGINEERS TESTING LABORATORIES, INC.

Paul H. Peters

Paul H. Peters, P.E.

/PO

COPIES TO: ADDRESSEE (4)

APPENDIX B

STRUCTURAL ANALYSIS

1675
CAVE CREEK DAM.
R.A.Y. 2-69.

MULTIPLE -
ARCH ANALYSIS.

REFERENCE - "STRESSES IN INCLINED ARCHES OF MULTIPLE ARCH DAMS" - ASCE VOL. 98 1933 PG 1200

1ST TRIAL SECTION 45' BELOW CREST OR EL. 1595.0

El.1595

SPACING OF BUTTRESS - 44'

EXTRADOS 24.2743' ; RISE = 14.015

THICKNESS 1.581'

θ = ∠ - GENERATOR OF BARREL TO HOR - 60.4°

WATER HT. 47.0'

WATER HEAD @ CROWN = $47 - 14.015 \cos 60.4 = 40.08'$

$p_e = 62.5(40.08) = 2505$ #/FT²

MEAN RADIUS = $24.2743 - .7905 = 23.4838$

$t/r = \frac{1.581}{23.4838} = .06732$

$\phi_1 = \text{ARC COS } \frac{24.2743 - 14.015}{24.2743} = \cos^{-1}\frac{10.2593}{24.2743} = \cos^{-1} .4226$

$= 65° \quad ; \quad 2\phi_1 = 130°$

$p_e r = 2505(23.4838) = 58826.9$

$p_e r^2 = 1,381,458$

UNIFORM WATER LOAD.

$P_0 = \left[\left(1 + \frac{t}{2r}\right) - Q_0\right] p_e r = 58,827 (1.024) = 60,239$

$P_1 = \left[\left(1 + \frac{t}{2r}\right) - Q_0 \cos\phi_1\right] p_e r = 58,827 (1.028) = 60,474$

$S_1 = p_e r Q_0 \sin\phi_1 = 58827(.015) .90631 = 800$

$M_0 = -p_e r^2 \left(1 - \frac{\sin\phi_1}{\phi_1}\right) Q_0 = -1,381,458(.002) = (-) 2,762.916$

$M_1 = p r^2 \left(\frac{\sin\phi_1}{\phi_1} - \cos\phi_1\right) Q_0 = 1,381,458(.0035) = 4,835.1$

VARIABLE WATER LOAD.

$w' = 62.5 \cos 60.4 = 30.9$ #/FT

$w' r_e^2 = 30.9(24.2743)^2 = 18,208$

$w' r_e^2 r = (18\,208)\,23.4838 = 427,405$

1675
CAVE CREEK DAM.
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ARCH ANALYSIS

$P_0 = w' r_e^2 Z = 18208(.0925) = 1,684$

$P_1 = w' r_e^2 (Z_1) = 18208(.1025) = 1,866$

$M_0 = w' r_e^2 r Z_2 = 427,405(.0057) = 2,436$

$M_1 = w' r_e^2 r Z_3 = 427,405(.0155) = 6,624.8$

$S_1 = w' r_e^2 Z_4 = 18208(.13) = 2,367$

DEAD WEIGHT

$w'_c = 150 \cos 60.4 = 74$ #/FT

$w'_c t r = 74 (1.581)(24.2743) = 2840.$

$w'_c t r^2 = 74 (1.581)(24.2743)^2 = 68,915$

$P_0 = w'_c t r Z' = 2840 (.802) = 2278$

$P_1 = w'_c t r Z'_1 = 2840 (1.392) = 3953$

$M_0 = w'_c t r^2 Z'_2 = 68,915 (-.0138) = -951$

$M_1 = w'_c t r^2 Z'_3 = 68,915(-.025) = -1723$

$S_1 = w'_c t r Z'_4 = 2840(-.25) = -710$

TEMPERATURE DROP

$\epsilon = .0000055$ $E_c = w^{1.5} 33 \sqrt{f'_c} = 330,000$ FOR $f'_c = 5000$

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CAVE CREEK DAM
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MULTIPLE
ARCH ANALYSIS

2nd. SECTION - 35' BELOW CREST ; EL. 1605±
El.1605
EXTRADOS = 24.2743'

THICKNESS = $\frac{1}{2}(1.408+1.052)$ = 1.23'

ANGLE - GENERATOR OF BARREL TO HOR. - 65.6°

WATER HT. @ SPRINGLINE = 37'

WATER HT. @ CROWN = 37 - 14.015 cos 65.6° = 37-5.8 = 31.2'

$P_e = 62.5(31.2) = 1950$ #/FT²

MEAN RADIUS = 24.2743 - .615 = 23.6593

$t/r = \frac{1.23}{23.6593} = .052$ $2\phi = 130°$

UNIFORM WATER LOAD.

$P_e r = 1950\ (23.6593) = 46136$

$P_e r^2 = 1950\ (23.6593)^2 = 1,091,400$

$P_0 = 1.02\ (46,136) = 47059$

$P_1 = 1.021\ (46136) = 47059$ (corrected: 1.029, 47600)

$S_1 = .006\ (46136) \cdot .906 = 245.4$

$M_0 = .00125\ (1,091,400) = 1364.2$

$M_1 = .0024\ (1,091,400) = 2619$

VARIABLE WATER LOAD.

$w' = 62.5\ \cos 65.6 = 25.8$ (cos = .4131)

$w' r_e^2 = 25.8 \times 24.2743^2 = 15,195.7$

$w' r_e^2 r = 15196\ (23.6593) = 359,527$ (25.8 struck out)

$P_0 = .0925 \times 15,196 = 1406$

$P_1 = .1025 \times 15196 = 1558$

$M_0 = .0057 \times 359,527 = 2049$

$M_1 = .0153 \times 359,927 = 5501$

$S = .129 \times 15196 = 1960$

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CAVE CREEK DAM
R.A.Y. 2-69

ARCH ANALYSIS.
EL. 1605.0
DEAD WEIGHT.

$W_c' = 150 \cos 65.6 = 62$ #/FT.

$W_c' t r = 62 (1.23)(23.6593) = 1804$

$W_c' t r^2 = 62 (1.23)(23.6593)^2 = 42687$

$P_0 = .809 (1804) = 1459$

$P_1 = 1.37 (1804) = 2471$

$M_0 = -.0123 (42687) = -525.1$

$M_1 = -.028 (42687) = -1195$

$S_1 = -.25 (1804) = -451$

ARCH ANALYSIS
EL. 1615
El. 1615
3rd SECTION - 25' BELOW CREST

EXTRADOS = 24.2743

THICKNESS = 1/2(1.052+1.0) = 1.026'

ANGLE GENERATOR OF BARREL TO HOR. - ~~70°~~ 71°21'

WATER HT. @ SPRINGLINE = 27'

WATER HT. @ CROWN = 27-14.015 COS 70° = ~~22.2~~ 22.52 (4.48, 4.8, .3198, 1408)

$P_e = 62.5(22.2) = 1389$ #/FT²

MEAN RADIUS = 24.2743 - .513 = 23.7613'

$\frac{t}{r} = \frac{1.026}{23.7613} = .0432$

UNIFORM WATER LOAD

$P_e r = 1389(23.76) = 32,950$

$P_e r^2 = 1389(23.76^2) = 780,000$

$P_0 = 1.018(32,950) = 33450$

$P_1 = 1.02(32,950) = 33600$

$S_1 = .005(32,950).906 = 149.1$

$M_0 = .0008(780,000) = 624$

$M_1 = .0015(780,000) = 1170$

VARIABLE WATER LOAD

$w' = 62.5 \cos 70° = 21.4$ (71.35°, 20)

$w' r_e^2 = 21.4(24.2743^2) = 12590$

$w' r_e^2 r = 12590(23.76) = 298,400$

$P_0 = 12,590(.0925) = 1163$		1086
$P_1 = 12,590(.1025) = 1290$		1202
$M_0 = 298,400(.0057) = 1701$		1589
$M_1 = 298,400(.0153) = 4570$		4260
$S = 12,590(.129) = 1622$		1512

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CAVE CREEK DAM
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ARCH ANALYSIS

EL. 1605. (CONT.)

DEAD WT.

$W_c' = 150 \cos 70° = 51.4$ #/FT² (71.34, 48.0)

$W_c' tr = 51.4(1.026)\ 23.76 = 1{,}250$

$W_c' tr^2 = 1250\ (23.76) = 29{,}650$

$P_0 = 1250\ (.8115) = 1015$ 948

$P_1 = 1250\ (1.37) = 1712$ 1599

$M_0 = 29650(-.0118) = -350$ 327

$M_1 = 29650(-.0288) = -854$ 798

$S_1 = 1250\ (-.026) = -32.5$ 304

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CAVE CREEK DAM
R.A.Y. 2-67

ARCH ANALYSIS
EL 1625
4TH SECTION -15' BELOW CREST
EXTRADOS 24.2743'
THICKNESS = 1.0'
∠ GENERATOR OF BARREL TO HOR. = 77° (77.33°)
WATER HT. @ SPRINGLINE = 17'
WATER HT @ CROWN = 17 - 14.015 COT 77 = 13.84 (3.16)

$p_e = 62.5\,(13.84) = 865$ #/FT²

MEAN RADIUS = 24.2743 - .5 = 23.7743

$t/r = \frac{1.000}{23.7743} = .0421$

UNIFORM WATER LOAD.

$p_e r = 865(23.77) = 20,500$

$p_e r^2 = 865(23.77)^2 = 487,000$

$P_0 = 20,500\,(1.018) = 20,850$

$P_1 = 20,500\,(1.02) = 20,920$

$S_1 = 20,500(.005) = 102$

$M_0 = -487,000(.0008) = -389.5$

$M_1 = 487,000(.0015) = 730$

VARIABLE WATER LOAD.

$w' = 62.5$ COT 77° = 14.08

$w' r_e^2 = 14.08(24.2743^2) = 8300$

$w' r_e^2 r = 8300\ (23.77) = 197,200$

$P_0 = 8300\,(.0925) = 768$

$P_1 = 8300\,(.1025) = 851$

$M_0 = 197,200\,(.0057) = 1123$

$M_1 = 197,200(.0153) = 3180$

$S = 8300\,(.129) = 1071$

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CAVE CREEK DAM.
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ARCH ANALYSIS
EL. 1625 (CONT.)
DEAD WT.

$W_c' = 150 \cos 77° = 33.75$

$W_c' t r = 33.75(1.0)(23.77) = 801$

$W_c' t r^2 = 801(23.77) = 19,010$

$P_0 = 801(.812) = 651$

$P_1 = 801(1.37) = 1098$

$M_0 = 19010(-.0117) = -222.1$

$M_1 = 19010(-.029) = -551$

$S_1 = 801(-.26) = -208.2$

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CAVE CREEK DAM
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ARCH ANALYSIS

STRESSES (W/O TEMPERATURE)

EL. 1595

CROWN. $\begin{matrix} f_i \\ f_e \end{matrix} = \frac{64201}{1.583} \mp \frac{1278}{.4165} = 40,500 \mp 3068 = \begin{matrix} 37432 \\ 43568 \end{matrix}$ PSF

$= \begin{matrix} 260 \\ 303 \end{matrix}$ PSI

ABUTMENT $\begin{matrix} f_e \\ f_i \end{matrix} = \frac{66293}{1.583} \pm \frac{9737}{.4165} = 41,850 \pm 23,378 = \begin{matrix} 65,228 \\ 18,472 \end{matrix}$

$= \begin{matrix} 453 \\ 128 \end{matrix}$ PSI

EL. 1605

CROWN $\begin{matrix} f_i \\ f_e \end{matrix} = \frac{49924}{1.23} \pm \frac{160}{.252} = 40,589 \pm 635 = \begin{matrix} 41,224 \\ 39,954 \end{matrix}$ PSF

$= \begin{matrix} 286 \\ 277 \end{matrix}$ PSI.

ABUTMENT $\begin{matrix} f_e \\ f_i \end{matrix} = \frac{51088}{1.23} \pm \frac{6925}{.252} = 41,535 \pm 27,480 = \begin{matrix} 69015 \\ 14055 \end{matrix}$ PSF

$= \begin{matrix} 479 \\ 97 \end{matrix}$ PSI

EL. 1615

CROWN. $\begin{matrix} f_i \\ f_e \end{matrix} = \frac{35480}{1.026} \pm \frac{638}{.175} = 34581 \pm 3646 = \begin{matrix} 38227 \\ 30935 \end{matrix}$ PSF $= \begin{matrix} 265 \\ 215 \end{matrix}$ PSI

ABUTMENT $\begin{matrix} f_e \\ f_i \end{matrix} = \frac{36401}{1.026} \pm \frac{4632}{.175} = 35479 \pm 26469 = \begin{matrix} 61948 \\ 9010 \end{matrix}$ PSF $= \begin{matrix} 430 \\ 63 \end{matrix}$ PSI

EL 1625

CROWN $\begin{matrix} f_i \\ f_e \end{matrix} = \frac{22269}{1.000} \pm \frac{511}{.1667} = 22269 \pm 3065 = \begin{matrix} 25334 \\ 19204 \end{matrix}$ PSF $= \begin{matrix} 176 \\ 133 \end{matrix}$

ABUTMENT $\begin{matrix} f_e \\ f_i \end{matrix} = \frac{22899}{1.000} \pm \frac{3359}{.1667} = 22899 \pm 20,150 = \begin{matrix} 43049 \\ 2749 \end{matrix}$ PSF $= \begin{matrix} 399 \\ 19.1 \end{matrix}$

$r_c = 24.2743'$ $2\phi = 130°$

ELEV.	LOADING	t, A	t/r	S t²/L	P_o LBS	P_1 LBS	M_o FT LBS	M_1 FT. LBS	S_1 LBS	STRESSES CROWN EXTRADOS PSI	CROWN INTRADOS PSI	ABUTMENT EXTRADOS PSI	ABUTMENT INTRADOS PSI
1595	UNIFORM WATER LD.	1.581	.0673	.4165	60239	60474	-2763	4835	800				
	VARIABLE WATER LD.				1684	1866	2436	6625	2367				
	DEAD LOAD				2278	3953	-951	-1723	-710				
	SUM				64,201	66,293	-1278	9737	2457	303	260	453	128
	TEMP. DROP												
	TOTAL												
1605	UNIFORM H_2O LD.	1.23'	.052	.252	47059	47059	-1364	2619	245				
	VARIABLE H_2O LD.				1406	1558	2049	5501	1960				
	DEAD LOAD				1459	2471	-525	-1195	-451				
	SUM				47924	51088	+160	6925	1754	277	286	479	97
	TEMP. DROP												
	TOTAL												
1615	UNIFORM H_2O LD.	1.026	.043	.175	33450	33600	-624	1170	149				
	VARIABLE H_2O LD.				1086	1202	1589	4260	1512				
	DEAD LOAD				948	1599	-327	-798	-304				
	SUM				35484	36401	.638	4632	1357	215	265	430	63
	TEMP. DROP												
	TOTAL												
1625	UNIFORM H_2O LD.	1.000	.0421	.1667	20850	20920	-390	730	102				
	VARIABLE H_2O LD.				768	851	1123	3180	1071				
	DEAD LOAD				651	1098	-222	-551	-208				
	SUM				22269	22899	511	3359	965	133	176	399	.19.1
	TEMP. DROP												
	TOTAL												

ARCH ANALYSIS

SUMMARY OF MOMENTS & STRESSES IN ARCH.

1675
CAVE CREEK DAM
R.A.Y. 2-69

ARCH SLOPE VARIATION

30.375
− 23.625 = 6.750
− 16.875 = 6.750
− 11.250 = 5.625
− 6.75 = 4.50
− 3.375 = 3.375
− 1.125 = 2.250

$\theta = TAN^{-1}\frac{10}{d} =$ $\cos\theta$

$\theta_{10} = TAN^{-1}\frac{10}{1.125} = 8.8889 = 83^\circ 35'$

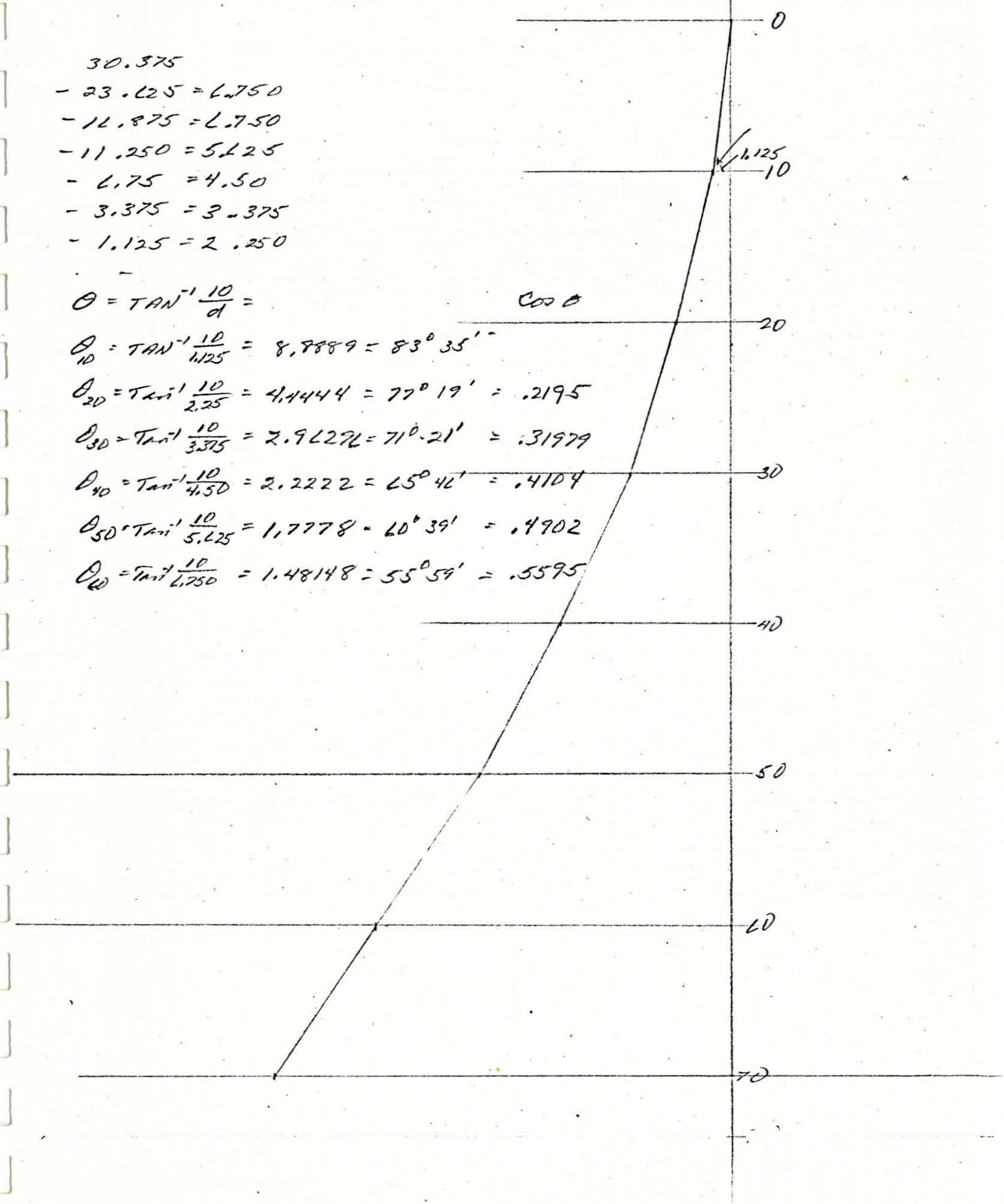
$\theta_{20} = Tan^{-1}\frac{10}{2.25} = 4.4444 = 77^\circ 19' = .2195$

$\theta_{30} = Tan^{-1}\frac{10}{3.375} = 2.96296 = 71^\circ 21' = .31979$

$\theta_{40} = Tan^{-1}\frac{10}{4.50} = 2.2222 = 65^\circ 46' = .4104$

$\theta_{50} = Tan^{-1}\frac{10}{5.625} = 1.7778 = 60^\circ 39' = .4902$

$\theta_{60} = Tan^{-1}\frac{10}{6.750} = 1.48148 = 55^\circ 59' = .5595$



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CAVE CREEK DAM.
R.A.Y. 3-69.

BUTTRESS ANALYSIS
REFERENCE ASCE VOL. 87 - 1924 Pg. 402,403

BY MONOLITH METHOD.
MAX. STRESS @ CROWN = -2.4 TONS/FT²
= -4800 #/FT²
= -33.3 PSI

½" # BARS @ 5' O.C. E.F.
$A_s/FT = \frac{.25}{2.5} = .1$ IN²/FT.

f_s = 48,000 PSI - TOO HIGH.

∴ ARCHS WILL DEFLECT UNTIL ABUTMENTS CARRY FULL LOAD

BY FREE-BODY BUTTRESS METHOD:
MAX STRESS @ HEEL = 29.9 TONS/FT²
= 415 PSI - O.K.

MINI. COMPRESSIVE STRENGTH OF TEST CORES = 2953 PSI   MAX = 4061 PSI.

∴ 415 < 1350 PSI ALLOWABLE.

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CAVE CREEK DAM.
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BUTTRESS ANALYSIS

HIGH WATER LINE = 1637.5 - REF. SURVEY BY YOST & GARDNER ENGRS. - 1922

ASSUME HIGH WATER @ 1638.5

SHEAR @ 20' BELOW CREST

HT. OF WATER = 1638.5 - 1620.0 = 18.5'

$F = 62.4(44)\frac{1}{2}(18.5)^2 = 472\ K = 236\ T$

SHEAR = $235 \frac{236}{332}$ = 167 PSI < 240 PSI (PURE SHEAR)

∴ AVG. SHEAR IS ~71% OF ORIGINAL DESIGN SHEAR

ASSUMING A .80 COEF. OF FRICTION FOR BUTTRESS SLIDING

RESISTING FORCE = .8(183.6) = 146.88 T. (DEAD WT. ONLY.)

= .8(292.2) = 234 T (DEAD + WATER WT W/O UPLIFT.)

SLIDING FACTOR*

HORIZONTAL FORCE VS VERTICAL FORCE @ DIFFERENT ELEV. $\tan \phi = \frac{HOR}{VERT}$ < INCLINATION OF FACE

REF. P. 402 OF ASCE VOL. 87.

DIST. BELOW 1640.	HORIZ. FORCE (TONS)	(W/O UPLIFT) TOTAL VERT. LOAD (INCLUDE WATER)	Tan φ	
10	99	59	1.68	
20	332	183.6	1.81	
30	705	377	1.87	~ > COEF. OF FRICTION
40	1210	690	1.75	2.20
50	1850	1175	1.572	1.76
60	2640	1858	1.42	

* Ref. pg. 579 "Engineering For Dams", Hinds, Creager, & Justin

1675
CAVE CREEK DAM
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BUTTRESS ANALYSIS.
REF. P. 297 - "ENGR. FOR DAMS." - (H, C & J)
RESISTANCE TO SLIDING (SHEAR INCLUDED)
SAFTY FACTOR

$$= \frac{f \Sigma (W) + r S_s A}{\Sigma P}$$

WHERE
$f = .7$ - FRICTION FTR
$r \approx .5$ - RATIO AVG. TO MAX. SHR STRESS
$S_s = 300$ PSI

$$\therefore S.F. = \frac{.7 \Sigma W + .5(300) A}{\Sigma P}$$

$$= \frac{.7 \Sigma W + 150 A}{\Sigma P}$$

WATER HT. @ EL. 1642.0

DIST. BELOW EL. 1640	KIPS ΣW	KIPS ΣP	FT^2 A	④ $.7 \Sigma W$	⑤ 21.6 .150(144)A	④ + ⑤	S.F.
10	108	198	8,125	75.6	175,5	251,1	1,27
20	367,2	662	19,56	257	422,5	679,5	1,026
30	754	1410	43,38	527,8	937,0	1464,8	1,039
40	1380	2420	79,47	966	1716,5	2682,5	1,108
50	2350	3700	129,94	1645	2807	4452	1,203
60	3716	5280	196,95	2601,2	4254	6855	1,298
70	5296	7120	277.63	3987.2	5997	9984,2	1.402

ASSUME HT OF WATER @ EL. 1658.5 - RATIO $\frac{h_1^2}{h^2}$

	RATIO	S.F
10	~~.707~~ .501	2,53
20	.707	1,45
30	.793	1,31
40	.840	1,32
50	.870	1,38
60	.890	1,46
70	.951	1,47

$\therefore$ S.F. ARE MUCH LOWER THEN RECOMMENDED 4 OR 5