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ANALYSIS OF UTILIZATION OF GROUT AND GROUT CURTAINS — MORROW POINT DAM

February 1986

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16. ABSTRACT

The foundation grouting program at Hungry Horse Dam was one of six large Bureau of Reclamation dams which was reviewed and analyzed. The purpose of this program was to analyze the use of foundation grouting in Bureau structures to determine the effectiveness of the grout over the service life of the dams to date. Special attention was given to preconstruction geological conditions and changed or unexpected geological conditions discovered during the grouting activities.

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a. *DESCRIPTORS*-- grouting*/ cement grouts*/ dam foundations/ grout curtains/ grouting pressure/ grout take/ foundation grouting/ grout mixtures

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ANALYSIS OF UTILIZATION OF GROUT AND GROUT CURTAINS– MORROW POINT DAM

by

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Concrete and Structural Branch
Division of Research and Laboratory Services
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Denver, Colorado

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UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

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ANALYSIS OF UTILIZATION OF GROUT AND GROUT CURTAINS

MORROW POINT DAM

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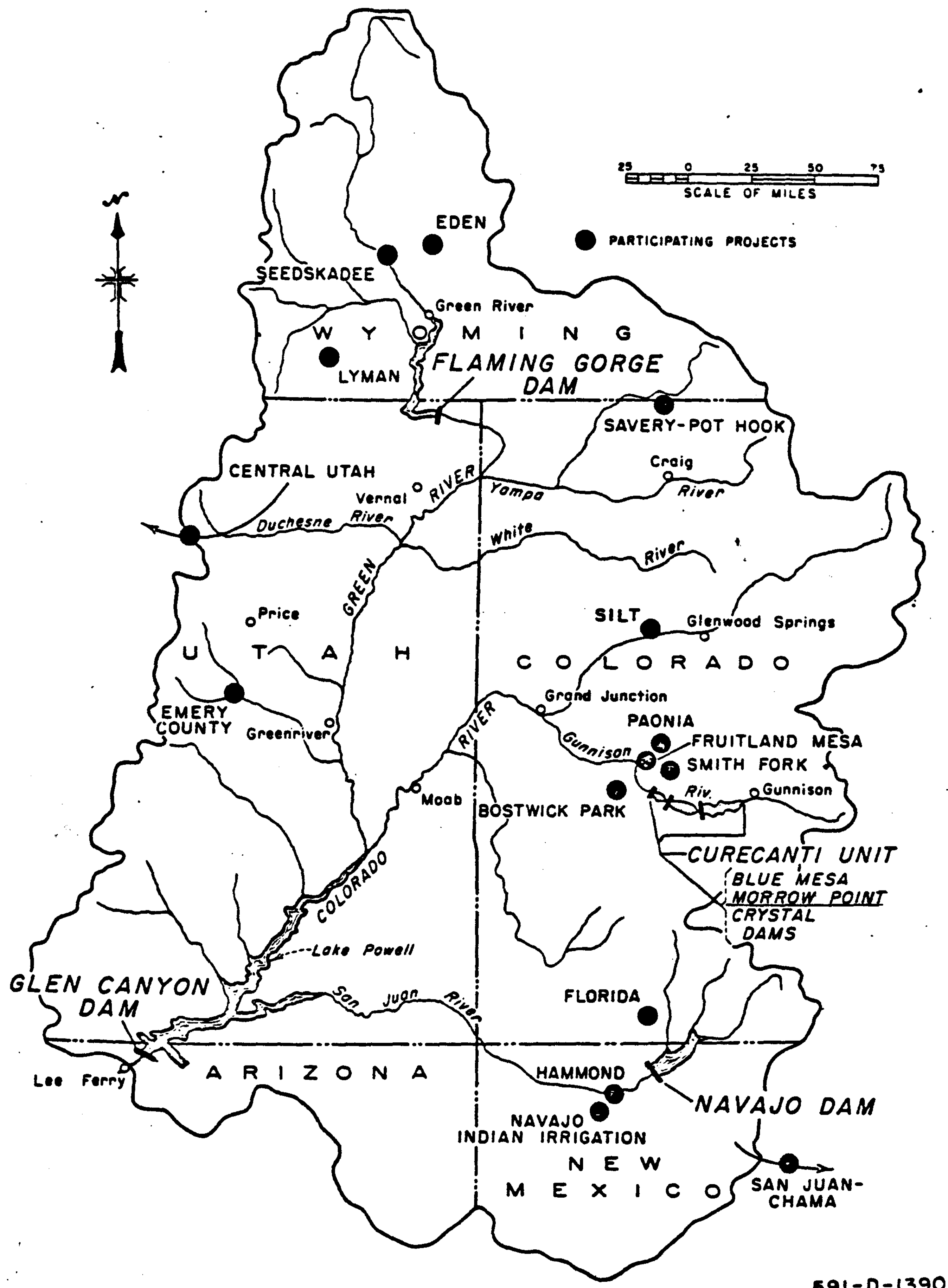
MORROW POINT DAM

I. INTRODUCTION

1. General description. Morrow Point Dam is located on the Gunnison River in west central Colorado about 22 miles east of Montrose, Colorado. See figure 1. The dam is a double-curvature, thin-arch concrete structure. It has a structural height of 469 feet above the lowest point in the foundation. The crest of the dam is at El. 7,165 feet. At the crown center, the dam has a width of 12 feet at the crest and a width of 52 feet at the base. The maximum water surface is at El. 7,165 and the minimum tail-water is at El. 6,755.8, resulting in a maximum differential head of 390.8 feet. The reservoir is operated for generating peaking power and is normally held at El. 7,160 thus maintaining a near maximum head on the dam most of the time. The plan and elevation of the dam are shown on figure 2, and a section through the dam is shown on figure 3.

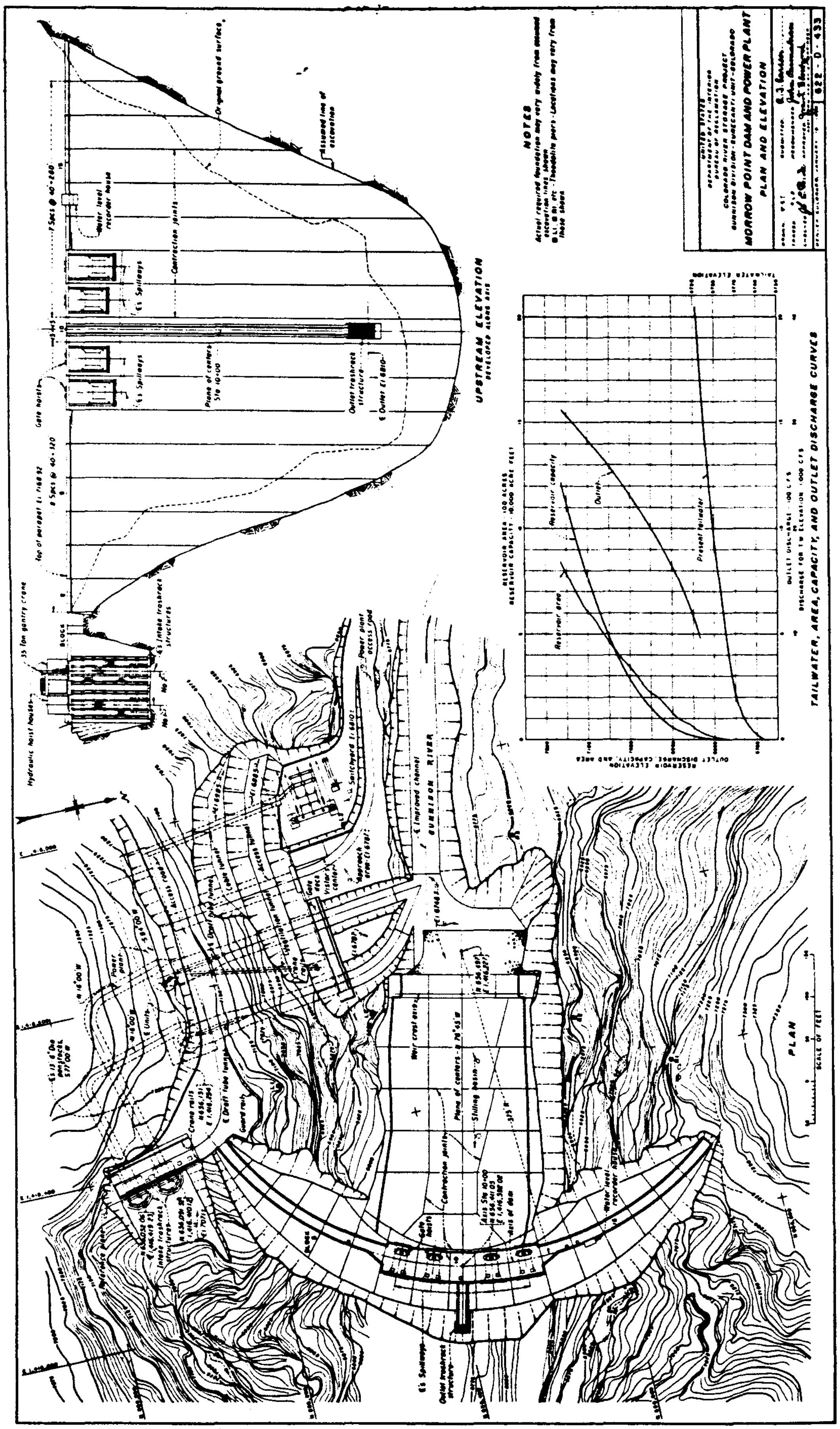
Most water is released from the reservoir through the power-plant which is located underground at the toe of the left abutment downstream of the dam. Water is supplied to the powerplant through two 13.5-foot-diameter penstock steel liners in 18-foot-diameter tunnels through the left abutment.

The outlet works is located about 63 feet above streambed and consists of a 4-foot by 4-foot stainless-steel lined conduit



Colorado River Storage project location map.

FIGURE 1


MORROW POINT DAM AND POWER PLANT
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UPSTREAM ELEVATION
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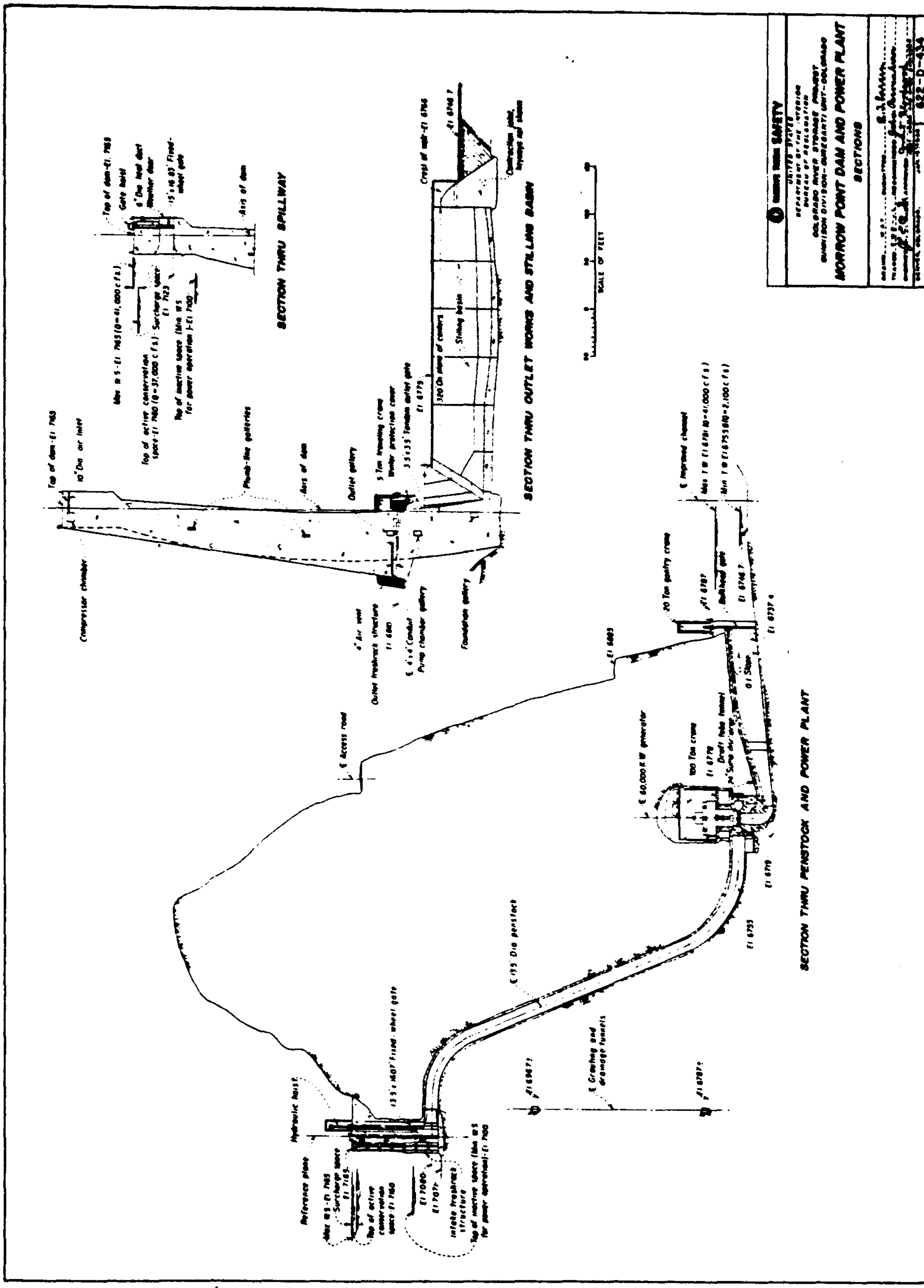
FIGURE 2


SECTION THRU SPILLWAY
SECTION THRU OUTLET WORKS AND STILLING BASIN
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622-D-434

FIGURE 3

through the center of the dam. The outlet works is gated on the discharge end and discharges into the concrete-lined stilling basin at the toe of the dam. The spillway consists of four formed 15-foot by 15-foot submerged openings near the top central portion of the dam. Each opening is controlled by a 15-foot by 16.83-foot fixed-wheel gate. The spillway discharge falls about 400 feet into the concrete-lined stilling basin at the toe of the dam as shown on figure 3.

The contract for the dam was awarded on May 14, 1963 to a joint venture of Al Johnson Construction Co. and Morrison-Knudsen Co., Inc. and the work was completed in 1968. Drilling and grouting were performed under a subcontract by Continental Drilling Co. Asphaltic grouting of the left abutment was done during the summer of 1969 under contract by Gunther and Shirley Co. Additional cement grouting of the left abutment was accomplished during the period of November 1969 to February 1970.

Excavation during construction involved removal of about 90 feet of alluvial material in the streambed. The work area was protected by upstream and downstream earthen cofferdams. The river flow was diverted through a tunnel excavated through the right abutment. The diversion tunnel was closed and sealed in January 1968.

2. <u>Consultants</u>. A board of consultants was engaged on the project. The available records only refer to one meeting of the board that was held in June 1963, which was shortly after the contract was awarded for the dam. The board was the same as the Flaming Gorge board and consisted of:

Julian Hinds, Chairman
Raymond E. Davis
John W. Vanderwilt
John J. Hammond
Edward B. Burwell, Jr.

II. GEOLOGY

3. Geologic setting. The Gunnison River above Morrow Point Dam drains an area underlain by Pre-cambrian igneous and metamorphic rocks and Mesozoic sediments. Tributaries from the north and south generally drain areas underlain by Tertiary volcanics. The project is located in a transition zone between two physiographic provinces, the Southern Rocky Mountains on the east and the Colorado Plateau on the west. The geologic setting for the project is described in detail by Logan and Wantland in a published technical report[1], and therefore will not be reported here.

4. Site geology. Morrow Point Dam is located in a steep rugged canyon which was cut through the Black Canyon uplift by the Gunnison River. Principal geomorphic features result from stress relief jointing, mechanical weathering, and mass wasting of the massive to blocky metamorphic and igneous rock. Talus slopes, slopewash, and scattered landslides involving both overburden and bedrock, represent minor geologic features in the canyon, but did receive significant engineering consideration during project design. The dam is located in a narrow reach of the gorge which prior to construction was about 200 feet wide at river level and over 600 feet wide at crest elevation. The canyon walls are nearly vertical to over-hanging and are separated by re-entrant benches or shelves. These features are shown in an aerial view of the site on figure 4 and a lower level upstream view of the site on figure 5.

Aerial view looking upstream at Morrow Point damsite. Dam abutments are approximately opposite the old narrow gage railroad bridge shown crossing the Gunnison River. P622B-427-2292, June 25, 1963.

FIGURE 4

Looking upstream at Morrow Point Damsite just beyond end of bridge

Figure 5

5. Rock types. The rock encountered at the damsite consists of alternating lenticular and irregular "beds" of biotite schist, mica schist, quartz-mica schist, and micaceous quartzite, all of which have been intruded by granitic pegmatite which ranges from small veinlets to massive intrusions. The hardness and strength of the rock types varies considerably, the hardest being the granite pegmatite and the micaceous quartzite with the other rock types grading downward in hardness to the weaker biotite schist. The quartz-mica schist comprised an estimated 55% of the total rock types encountered at the dam and the mica schist about 25%. The weaker biotite schist comprised only about 5% of the total. There was very little weathering at the site, except for moderate weathering of the biotite schist, which formed the narrow re-entrant benches or shelves on the canyon walls. Rock properties are summarized in table 1, which was reproduced from table 3-1 of the technical data book with the names of rock types added.

Alluvial fill in the valley bottom consisted of rounded sand, gravel, cobbles and boulders mixed with large angular talus blocks. The fill was approximately 50 feet deep in the center of the channel increasing in depth on the right side under the talus area.

6. Structure. (a) Synclinal fold. The damsite is located on the axis of a small synclinal fold which strikes N 15° W and plunges to the south (into the left abutment) at about 5°. The syncline forms a structural trough as expressed by the attitude of the foliation which dips toward the dam axis from both upstream and downstream. The upstream dip of the foliation toward the dam

Table 1. - Rock properties

	Type I	Type II	Type III	Type IV	Type V	Weighted average
Percent of rock mass in:	Biotite Schist	Mica Schist	Quartz Mica Schist	Micaceous Quartzite	Pegmatite	
Dam foundation	5	25	55	10	5	
Powerplant excavation	5	40	45	0	10	
Specific gravity	2.83	2.74	2.72	2.74	2.64	2.73
Specific weight	177 lb/ft^3	171 lb/ft^3	170 lb/ft^3	171 lb/ft^3	165 lb/ft^3	170 lb/ft^3
Density ( )	5.50 $\frac{lb/s^2}{ft^4}$	5.31 $\frac{lb/s^2}{ft^4}$	5.28 $\frac{lb/s^2}{ft^4}$	5.31 $\frac{lb/s^2}{ft^4}$	5.12 $\frac{lb/s^2}{ft^4}$	5.29 $\frac{lb/s^2}{ft^4}$
Young's modulus (E)	0.86×10^6 lb/in^2	1.19×10^6 lb/in^2	4.14×10^6 lb/in^2	8.84×10^6 lb/in^2	2.68×10^6 lb/in^2	2.65×10^6 lb/in^2
Poisson's ratio ( )	0.02	0.04	0.06	0.14	0.05	0.05
Shear modulus (G)	0.42×10^6 lb/in^2	0.57×10^6 lb/in^2	1.95×10^6 lb/in^2	3.88×10^6 lb/in^2	1.28×10^6 lb/in^2	1.25×10^6 lb/in^2
P wave velocity (Cp)	4,750 ft/s	5,700 ft/s	10,500 ft/s	15,400 ft/s	8,700 ft/s	8,202 ft/s
Cp	15.12 $\frac{lb/s}{in^3}$	17.52 $\frac{lb/s}{in^3}$	32.69 $\frac{lb/s}{in^3}$	47.32 $\frac{lb/s}{in^3}$	25.78 $\frac{lb/s}{in^3}$	25.10 $\frac{lb/s}{in^3}$
Unconfined compressive strength	3,170 lb/in^2	5,870 lb/in^2	14,990 lb/in^2	28,820 lb/in^2	15,070 lb/in^2	10.760 lb/in^2
Tensile strength	-	75 lb/in^2	480 lb/in^2	1,140 lb/in^2	870 lb/in^2	335 lb/in^2
Rock classification	Biotite schist	Mica schist	Micaceous quartzite	Quartzite	Pegmatite	

axis reduces the possibility of slippage along the schist beds from the thrust of the arch dam as shown on figure 6. The synclinal fold which strikes diagonally across the dam axis may have helped to contain grout travel along the foliation planes as the grout flow would be up-gradient in both directions from the dam axis.

(b) Joints. Stress relief joints were the most significant structural defect encountered at the dam site. The relief joints roughly paralleled the canyon walls. Less predominate high angle joint sets, low angle "lift" joints and foliation planes were also mapped and can be seen on figures 5 and 6, and on the geologic map of the area, figure 7. Three predominate joint sets mapped near the powerplant site were:

Set A-Strike N 63° W, dip 82° SW (principal stress relief set)

Set B-Strike N 36° E, dip 80° NW

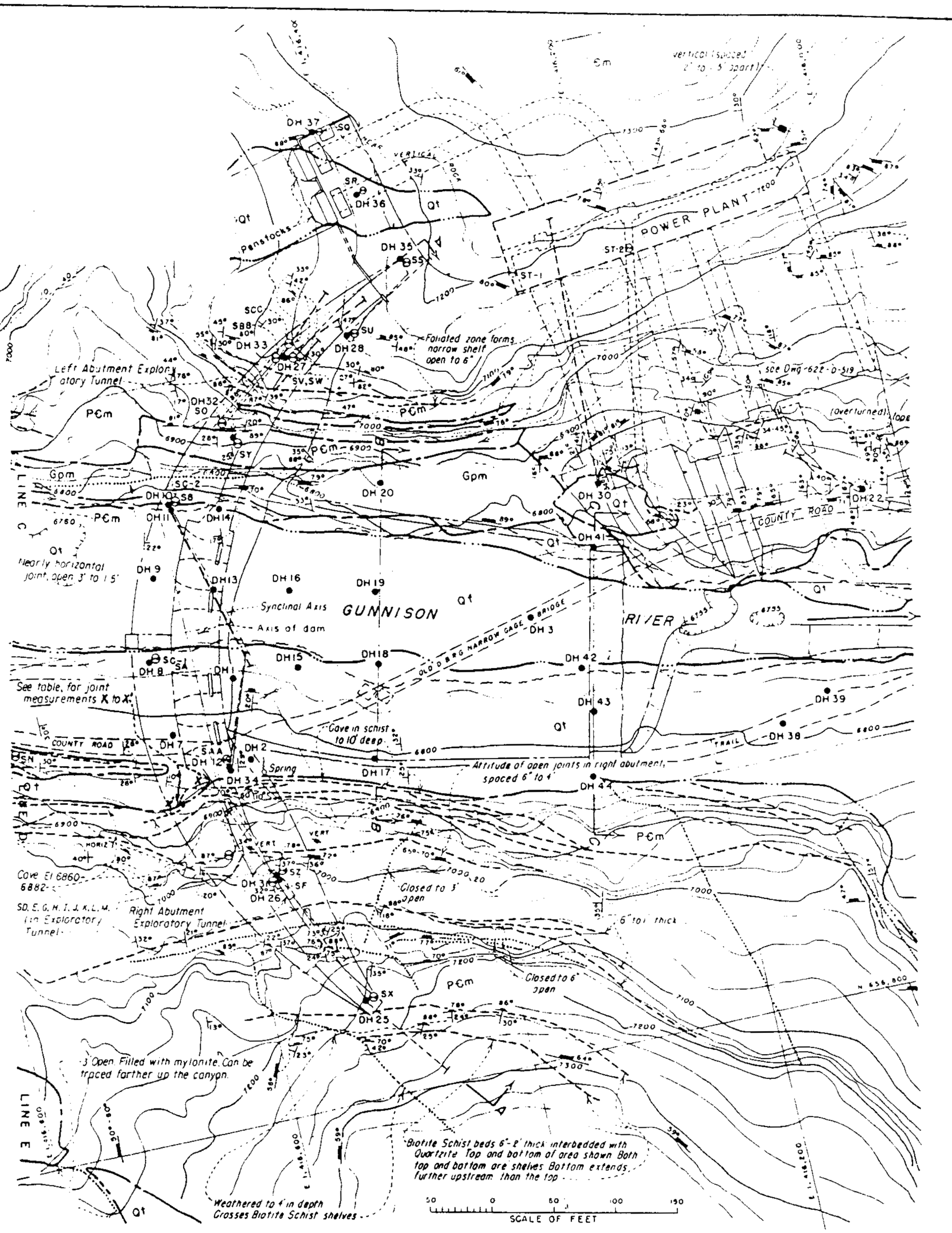
Set C-Strike N-S, dip 43° E

Also, twenty joints were mapped in detail along a 40-foot horizontal section X-X', from the dam axis upstream along the toe of the right abutment, as shown on figure 7 upstream from DH-34. These joints showed strikes ranging from N 64° W to N 80° W and dips ranging between 69° SW to 87° NE. Because these joint sets are nearest the dam foundation they may best represent the joint system in this area. These joints were spaced from 0.2 to 6.0 feet apart along section X-X' and were closed to open from 1/32 inch up to a maximum of 6 inches. It is assumed that section X-X' was mapped prior to removal of rock to foundation grade.

Jointing, especially in structure excavations near or on the surface, had an important influence on the rock excavation

Figure 6

Morrow Point Damsite - Right abutment downstream of axis. Note: The dip of limb of syncline is toward dam axis.



EXPLANATION

Qt SAND, GRAVEL to BOULDERS (River Fill).

Qt GRAVEL to large BLOCKS of rock, angular, in SILT-SAND matrix (Talus).

PCm MICACEOUS QUARTZITE, QUARTZ MICA SCHIST, AUGEN GNEISS and BIOTITE SCHIST occurring in roughly parallel beds. All have been intruded by small to fairly large granite pegmatite dikes and sills

Gpm GRANITE PEGMATITE, massive, relatively unbroken to broken

— — MICA SCHIST beds 6" to 3' thick, soft and weathered at surface

······ Major open joints and shear zones

—·— Approximate boundary (controlled) between geologic materials.

—··— Approximate boundary (uncontrolled) between geologic materials.

Strike and dip of foliation. (overturned)

Strike and dip of jointing: Vertical joint

● DH Drill hole (angle hole indicating bearing and projected length.)

⊖ 58 Geophysical (Seismic) observation point or seismic spread. Points or spreads, SD, E, G, H, I, J, K, L, M, O, T-1, T-2, AB and CC are located in Exploratory Tunnels.

JOINT SPACING MEASURED NORMAL TO DIP.
LINE X TO X'

Spacing (ft)	Opening (in)
X — 5'	1/16"
7'	Closed
8'	1/32"
1.1'	1/4"
1.7'	Closed
2.7'	1"
1.1'	3"
6.0'	3"
4.9'	1/2"
.8'	1/4"
2'	Closed
7'	1"
2.7'	6"
1.4'	2"
1.7'	Closed
1.0'	Closed
1.9'	4"
2.1'	1/4"
2.0'	1/2"
X' — 2.8'	Closed

Joints continue but are widely spaced and closed to 1/4" open.
Joints strike N. 64° W to N. 80° W
Dip 69° S.W. to 87° N.E.

REF. DWG. GEOL. 63-306

CONTRACT NO. 2-07-DV-00148

U. S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
GROUTING RESEARCH PROGRAM

MORROW POINT DAM
SURFACE GEOLOGY AND
LOCATION OF EXPLORATION

PREPARED BY: CLAUDE A. FETZER
JULY 1982 CONSULTING GEOTECHNICAL ENGINEER

FIGURE 7

with the most important being the stress relief joints. Practically all the construction of above ground features on the left side of the river experienced difficulties which could be attributed both directly and indirectly to the presence of stress relief joints. Major stress relief joints and shears are shown by dotted lines on the geology map on figure 7. Some of these features were over 350 feet in length and were open 3 to 4 feet or more at the surface. All but one of these features was located on the right abutment. The other one was located on the left abutment and was described as a nearly horizontal joint open from 3 inches to 1.5 feet, and running from 170 feet upstream of the dam axis to 45 feet downstream of the axis at El. 6,800+. On the geologic profile Section A-A on figure 8, this open horizontal feature appears to be closed or absent at the 6,800 elevation.

(c) Rebound of valley floor. Valley stress relief due to unloading was also expressed by a zone of fractured rock which extended to a depth of about 80 feet below the top of rock at the base of the valley alluvial fill.

(d) Shear zones. Two well developed shear zones were encountered in the powerplant area and two other possible shear zones were encountered in angle boring DH-12 at elevation 6,585± near the center of the dam axis and in DH-10 between elevations 6,735 and 6,745 located at the toe of the left abutment. Neither of these shear zones appear to carry through to adjacent borings and may represent near vertical shears striking in an upstream-downstream direction. Based on a projection of the strike and dip

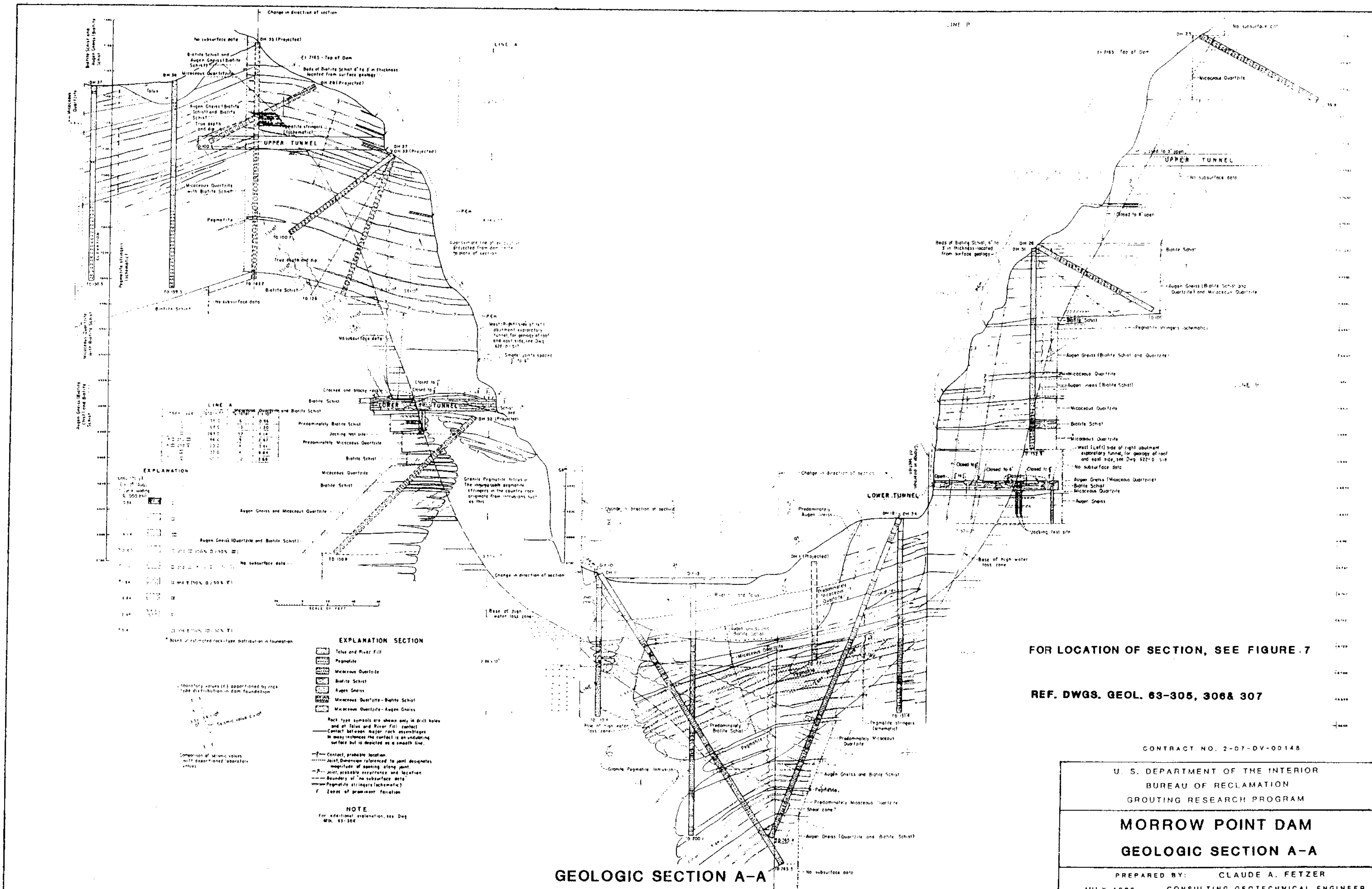

GEOLOGIC SECTION A-A
UPPER TUNNEL
LOWER TUNNEL
EXPLANATION SECTION
Talus and River Fill
Pegmatite
Micaceous Quartzite
Biotite Schist
Augen Gneiss
Micaceous Quartzite - Biotite Schist
Micaceous Quartzite - Augen Gneiss
NOTE
FOR LOCATION OF SECTION, SEE FIGURE 7
REF. DWGS. GEOL. 63-305, 306& 307
CONTRACT NO. 2-07-DV-00148
U. S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
GROUTING RESEARCH PROGRAM
MORROW POINT DAM
GEOLOGIC SECTION A-A
PREPARED BY: CLAUDE A. FETZER
JULY 1982 CONSULTING GEOTECHNICAL ENGINEER

FIGURE 8

of the two powerplant shear zones there does not appear to be any correlation of these with the shears found in DH-12 or DH-10.

7. Site investigations. Comprehensive geologic investigations included: (1) detailed geologic mapping, (2) diamond core drilling, (3) excavation of five exploration tunnels, (4) examination of drill holes by a television drill hole camera, and (5) seismic surveys.

Geologic studies were also coordinated with horizontal and vertical jacking tests, Whittemore strain gage measurements, borehole strain gage measurements, and extensive laboratory tests for absorption, tensile, compression and triaxial shear, and creep.

One hundred and eight core-drill holes were completed during the preconstruction investigation with a total footage of approximately 8,000 feet. Water losses in drilling the exploratory holes followed by water pressure tests provided data for estimating foundation grouting and for powerplant dewatering and drainage studies.

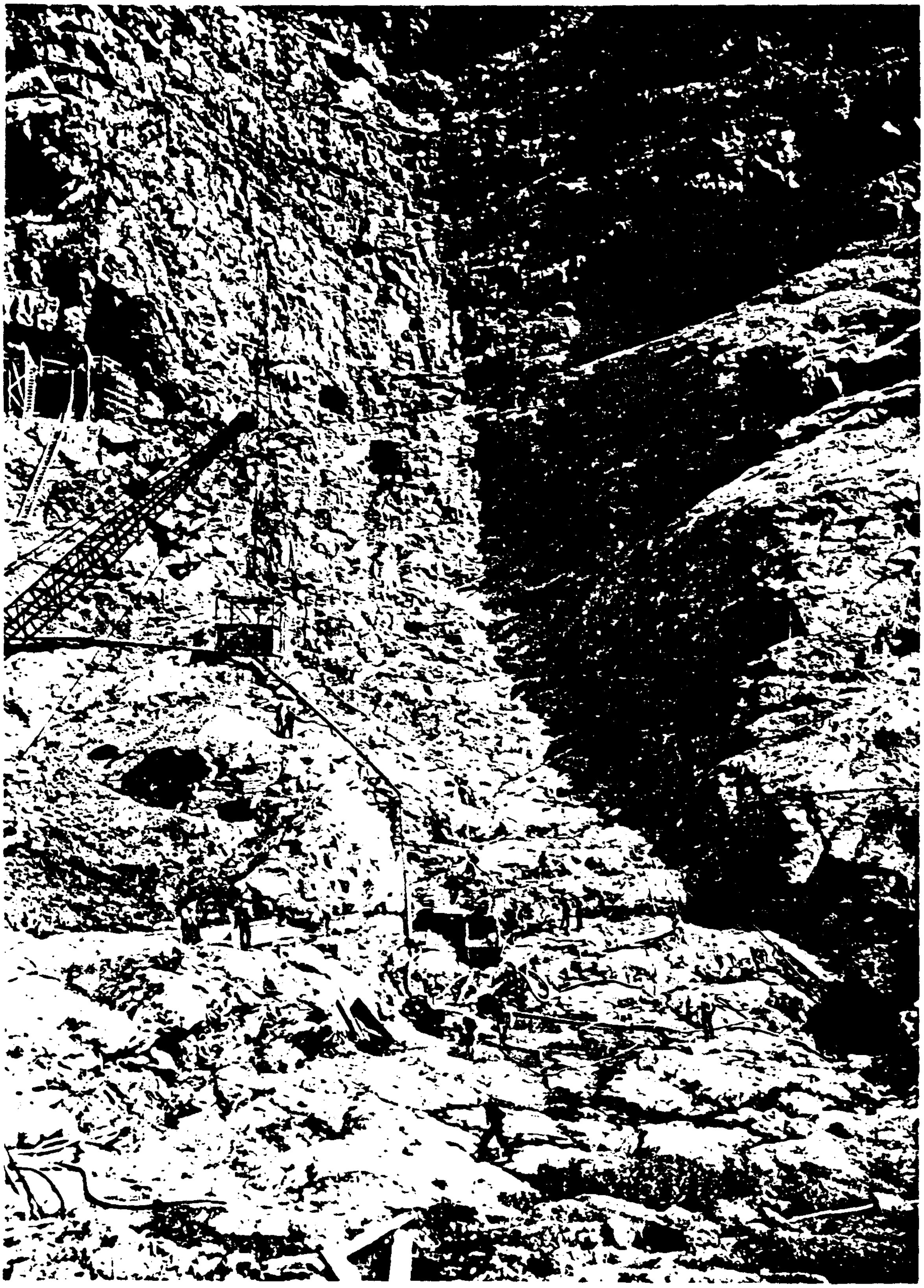
Five exploratory tunnels were excavated. Two tunnels in the dam foundation and one in the powerplant area were excavated during the preconstruction investigations. Two tunnels were excavated in the dam foundation during construction. These abutment tunnels provided data on the severity and orientation of the surface and stress relief-jointing and were also used as stations for seismic shots and sites for jacking tests. Four additional tunnels were excavated during construction for grouting and drainage.

III. FOUNDATION PREPARATION

8. Excavation. Abutment keyways were excavated to sound rock at average depths of about 60 feet measured normal to the canyon walls as shown in the photographs on figures 9 and 10 and on section A-A of figure 11. The rock in the valley floor was excavated to a depth of about 20 feet.

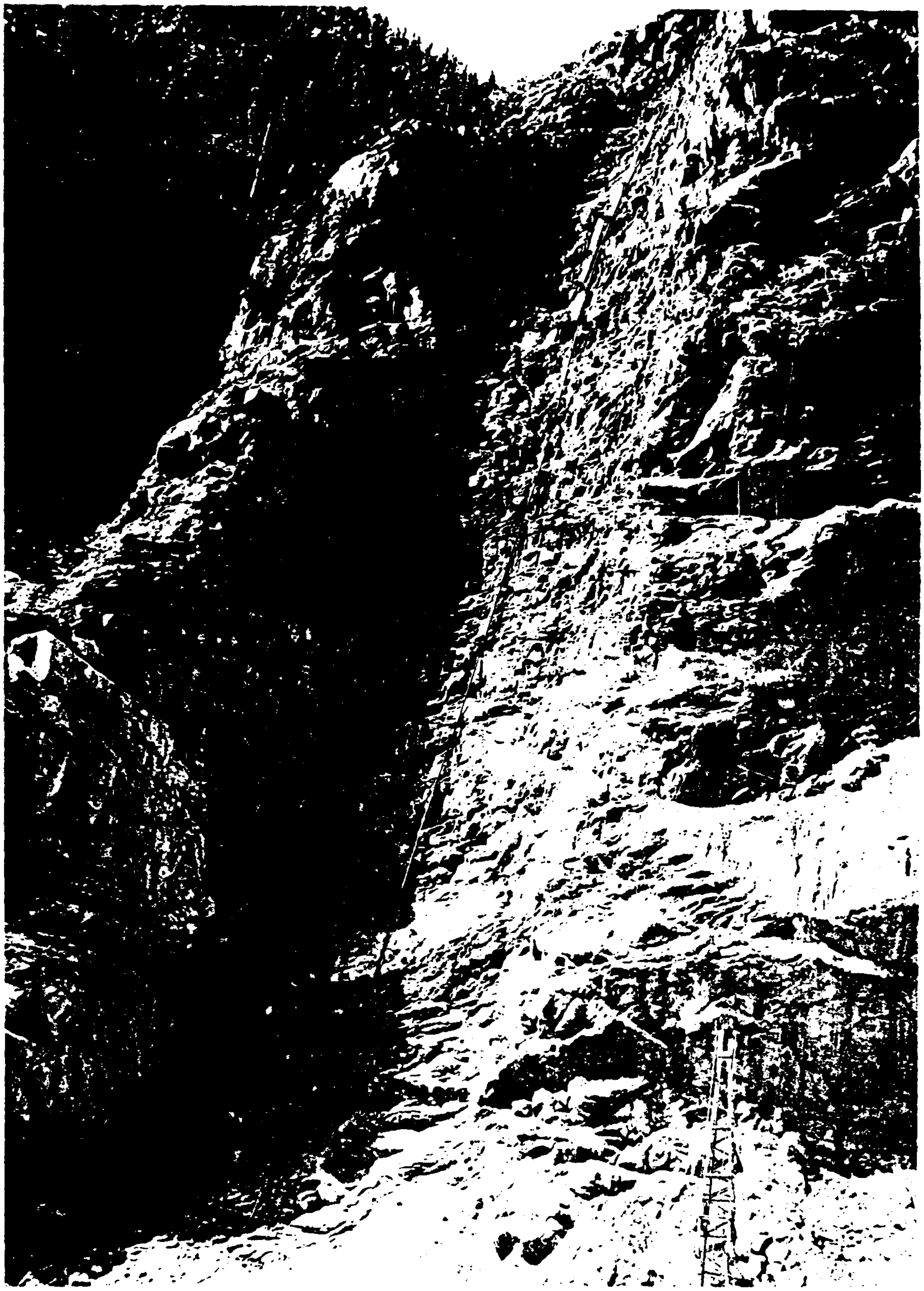
At the beginning of excavation of the left keyway, a series of stress relief joints located in the rock immediately downstream from the keyway were found to have an open width as much as 21 inches. These joints were the principal stress relief set having a strike N 65° W, and a near vertical dip, and extended northwest from dam axis station 6+75 nearly parallel to the canyon wall. There was concern that the keyway blasting might open these joints further. To record any construction induced movement in the jointed area, a series of chaining points and Whittemore strain gage sites were installed. No appreciable movement occurred. Seventy-eight 1-inch-diamater, groutable rock bolts ranging in length from 15 to 20 feet were installed in the area for stabilization.

A wet seam of clay gouge, 1 to 3 inches thick, was uncovered at elevation 7,090 feet on the toe of the left keyway. This seam had a general strike of N 50° E and dipped 20° southeast. It was traced across the entire keyway and into the penstock intake area. After leaving the keyway area, considerable variation in attitude was seen. A vertical joint near the dam toe indicated the rock above the seam had previously moved about 3 inches toward the southeast. A Whittemore strain gage site was located across this



P622B-427-3081 NA---Curecanti Unit---Morrow Point Dam---Colorado
View of the right keyway after excavation has been completed. Grouting is in progress. 8-4-65

Figure 9



P622B-427-3080 A---Curecanti Unit---Morrow Point Dam---Colorado
View looking at the left keyway after excavation has been completed. 8-4-65

Figure 10

seam to record any movement during construction. Also, the mass of rock above the seam and downstream from the toe between elevations 7,120 and 7,080 feet was rockbolted with thirty-two 1-inch groutable type rock bolts which ranged from 20 to 40 feet in length.

It was necessary to reslope the right keyway from elevation 7,120 to elevation 6,960 to avoid a zone of near-vertical open joints crossing the toe. These joints strike N 65° W. (The principal stress relief set).

Four grouting and drainage tunnels were excavated into each keyway during construction. The right keyway exploratory tunnel at elevation 7,085 feet was also used for grouting and drainage. These tunnels connected with the dam galleries and were located at invert elevations 6,965 and 6,785 on the left keyway and 6,815 on the right keyway. The tunnel elevation 6,785 in the left keyway extends to the powerplant and is utilized as an access between the dam and powerplant. The surrounding rock at each portal was rockbolted prior to the initial portal blast for stability and prevention of overbreak. The other three exploratory tunnels in the keyways were backfilled with concrete.

A review of the geology indicated that there were no potentially unstable rock masses in the foundation area. Loads from the dam were carried into the rock mass in such a manner that they did not induce instability of the foundation.

IV. GROUTING AND DRAINAGE

9. Reference. The chapter on Foundation Grouting, Drilling and Drainage from the Final Construction Report has been reproduced as appendix B. Reduced drawings are included for the design and installation of the drainage, dam-foundation B-holes, and A-holes; these drawings are referred to in the reproduced text. The as-built drainage drawing 622-427-1116 was substituted for 622-427-1899 as it included additional drains drilled later. Other drawings with appendix B, but not mentioned in the text, include: B-hole design, 622-D-835; left abutment extended curtain 622-D-2435 and 622-427-1118; and left abutment downstream drain holes 622-D-2388. Drawings for grouting of the stilling basin and other appurtenant structures were not included.

10. Design and installation. The general plan developed in the design stage was to use low-pressure consolidation grouting from the dam foundation followed by a high-pressure deep curtain grouting from the foundation tunnels and galleries. Drainage holes were also drilled from the tunnels and galleries.

(a) Foundation drainage. The general scheme was to drill the drainage holes inclined 10 degrees from the vertical in a downstream direction after the grouting was completed. The drain holes in the valley bottom extended about 60 feet below the base of the dam and below the base of the lowest tunnels. See drawing 622-D-1056. In the abutment the drain holes formed a curtain between the tunnels as shown on drawings 622-D-1057 and 1494. Drain holes were also drilled from the powerplant drainage tunnel which connected to the lowest tunnel (El. 6,785) on the left abutment. Drain holes were also drilled to help stabilize the left abutment downstream as shown on drawing 622-D-2388.

(b) Consolidation grouting. The basic scheme was to drill four lines of holes to cover the entire foundation area. The two upstream lines were to be 10 feet apart with the third line 20 feet downstream of the second line and the fourth line 20 feet downstream of the third line. However, the width between the lines was narrowed near the top of the dam to maintain four lines of grout holes. A fifth line was added where the foundation contact area was wide enough to accommodate a fifth line. The holes in the bottom were drilled normal to the rock surface and to a design depth of 70 feet. The holes on the abutments were drilled at an angle of 30 degrees from the vertical to a design line that was 50 feet in depth normal to the slope. In the actual installation the holes were drilled to depths ranging from 20 to 70 feet, and the holes were angled in various directions to intersect surfacing joints. Several holes were drilled deeper than 70 feet to a depth range of 90 to 110 feet with one hole in block 5 having a depth of 143 feet.

The distribution of takes for the B-hole foundation grouting is shown in table 2; the data were taken from page 3 of the Drilling and Grouting Operations (L-10) Report for the period from July 24, 1967 through August 22, 1967, and include all drilling and grouting except for three remaining holes on top of block 1, which evidently took 228 sacks. Blocks 1 through 6, constituting the left abutment, had a take of 18,121 sacks or 58% of the total B-hole take. Blocks 7 through 12, constituting the

Table 2

Summary* of Foundation B-hole Drilling and Grouting

Block	Period July 24 to August 23, 1967			Total to August 23, 1967		
	Drilling	Take		Drilling	Take	
	Lin. Ft.	No. Sacks	Sacks/Ft.	Lin. Ft.	No. Sacks	Sacks/Ft.
1	0	0	-	983	3,377	3.44
2	0	0	-	971	417	0.43
3	0	0	-	2,296	3,945	1.72
4	0	0	-	4,019	8,651	2.15
5	0	0	-	3,070	1,049	0.34
6	0	0	-	2,350	454	0.19
7	0	0	-	1,290	435	0.34
8	0	0	-	1,090	1,804	1.66
9	0	0	-	1,350	1,585	1.17
10	0	0	-	1,010	1,078	1.07
11	0	0	-	940	1,202	1.28
12	0	0	-	1,000	399	0.40
13	0	0	-	1,260	333	0.26
14	0	0	-	2,310	452	0.20
15	0	0	-	3,240	781	0.24
16	0	0	-	3,035	3,359	1.11
17	0	0	-	1,456	712	0.50
18	218	12	0.055	2,156	932	0.43
TOTAL	218	12	0.055	33,835	30,965	0.91

*Does not include three holes in block 1 that had a total take of 228 sacks.

valley bottom, had a take of 6,503 sacks or 21% of the total take. Blocks 13 through 18, constituting the right abutment, had a take of 6,569 sacks or 21% of the total take. Several holes on the left abutment had large takes including one hole on line 2-1/2, Station 7+64, El. 6,949, with a take of 3,457 sacks.

(c) Deep-curtain grouting. The A-holes for the deep curtain grouting were to be drilled and grouted after the B-hole grouting and after the concrete within a radius of 200 feet had been placed to a height of 120 feet above the foundation rock. The design grout curtain for the valley bottom showed grout holes extending to a maximum depth of 200 feet below the base of concrete with intermediate holes extending to depths of 100 and 150 feet. The holes on the left abutment were to be mostly drilled from the grouting and drainage tunnels at El. 6,785 and El. 6,965 extending 390 feet and 310 feet respectively into the abutment. Additional holes were to be drilled from the top of the dam. On the right abutment the A-holes were to be drilled into the abutment to a depth of 200 feet at the base and tapering to 100 feet at the top of the dam. The holes were to be inclined from the vertical about 30 degrees into the abutment. During the construction stage, it was decided to add three grouting and drainage tunnels in the right abutment at El. 6,815, El. 6,965 and El. 7,085 extending 230 feet, 170 feet and 90 feet respectively into the abutment.

The basic spacing of the A-holes was set at 10 feet with provisions for drilling on 5-foot centers and to depths of 310 feet if required by the contracting officer. Holes in the grouting and drainage tunnels were drilled parallel to the upstream-downstream direction with slight inclination upstream. The idea was to form a continuous curtain from drilling upwards and downwards from the tunnels. On the left abutment the holes from the tunnels were designed to bottom out at El. 6,840; and on the right abutment, the holes were designed to intercept the 200-foot depth line. The A-line holes were installed in accordance with the design developed during construction except that some holes were extended deeper than planned - see Drawings 622-427-1624, -1625, -1896 and -1897. The takes for the abutments and foundation are shown in the tabulation on page 406 of appendix B.

11. Specifications. The specifications were complete insofar as the general performance of the work, but the specifications did not contain minimum requirements for many items such as capacity of the pumps, mixing tubs and sump agitators, or the minimum diameter of grout tube through the packer.

12. Grouting methods and procedures. (a) Water pressure tests. All holes were required to be thoroughly tested with clean water under continuous pressure up to the required grouting pressure. The packers were required to provide a seal without leakage under the full water pressure for a period of 5 minutes, indicating that the water-pressure tests were for that period of time.

(b) Grout mixes. The data in appendix B indicate that water-cement ratios for the B-holes varied from 5:1 to 1:1 with most of the grout being 5:1. Grout mixtures for the A-holes varied from 7:1 to 1:1 water-cement ratio by volume with most of the grout pumped at a 7:1 mix.

(c) Grout injection pressures. The specifications indicate that pressures up to a maximum of 500 psi may be used in grouting. The data in appendix B indicate that the pressures used were as follows:

(1) B-Holes - Dam Foundation - Limited to 15 psi at the collar and increased one psi per-foot depth of hole to the packer.

(2) B-Holes - Stilling Basin Foundation - Same as for B-holes in dam foundation except for horizontal holes which were limited to 10 psi at the collar and increased one half psi per foot of depth of hole to the packer.

(3) A-Holes - Curtain Grouting - Pressure of 75 psi at the collar with a gradual increase of up to 500 psi depending upon depth of hole.

(d) Spacing of holes and closure. Grouting of B-holes was accomplished by the split-spacing method of closure with the primary holes on 40-foot centers. The average unit take of B-line holes from primary to final closure is not given in appendix B, but unit takes by grout lines show a reduction in unit take from 0.78 on the original lines to 0.18 on closure holes between the original and closure lines.

Grouting of the A-holes was also by the split-spacing method of closure. The tabulations of takes from three orders of closure are presented on page 407 of appendix B. If the final closure holes were on 10-foot centers, the primary holes would have been 80 feet.

No criteria were found in the available records for final spacing of holes or for determining that the curtain was tight.

(e) Refusal criteria. The requirements in the specifications were as follows:

> "The grouting of any hole shall be continued until the hole or grout connection takes grout at the rate of less than 1 cubic foot of the grout mixture in 20 minutes if pressures of 50 pounds per square inch or less are being used, in 15 minutes if pressures between 50 and 100 pounds per square inch are being used, in 10 minutes if pressures between 100 and 200 pounds per square inch are being used, and in 5 minutes if pressures in excess of 200 pounds per square inch are being used."

(f) Final backfilling of holes. The specifications did not include requirements for sounding and for final backfilling of completed grout holes. The grouting report in appendix B does not contain any record of this work.

13. Asphalt grouting and extended cement grouting of the left abutment. When the reservoir was being initially filled to El. 7,160, seepage in excess of 400 gpm developed in the powerplant drainage tunnel in the left abutment. There was also minor seepage along two prominent shear zones in the chamber excavated for the powerplant. Exploratory borings were drilled from the end of the El. 6,965 grouting and drainage tunnel and from the top of the left abutment. It was found that the seepage path was beyond the end of the existing grout curtain.

While lowering of the reservoir was being accomplished for vibration studies, grouting with catonic asphalt emulsion was attempted in the exploratory holes. The reservoir during the grouting period (July-September 1969) ranged from El. 7,075 to El. 7,050. Additional cement grouting was accomplished from November 1969 to February 1970 from the El. 6,965 tunnel and from the top of the dam as shown on Drawing 622-427-1118. The reservoir level ranged from El. 7,012 to El. 7,020 during the cement grouting. The asphalt grouting and cement grouting were described in a paper by Gebhart(2).

V. ANALYSIS

14. Preconstruction geologic investigations. The preconstruction geologic investigations for Morrow Point Dam were exceedingly thorough and complete. In contrast to several other dams in this study, the exploration tunnels and the drill holes were located along the final dam axis and at other appropriate locations. Except for the troublesome shears encountered in the powerplant excavations, rock conditions encountered during construction of Morrow Point varied only slightly from those predicted from the preconstruction investigations. The seepage path found as the reservoir initially filled was located landward of the geologic mapping and drill holes on the left abutment.

With regard to the grout curtain, there is no record on how the voluminous amount of geologic data was used to design the grout curtain. There is no record of any analysis of the geologic data being used to determine the extent of the grout curtain into the abutments or foundation, or to determine the angles and spacings of the holes, or to estimate the grout quantities. There is no record of a geologic or hydrogeological model being made to show the relationship of the spacing, attitude and openness of joints and foliation planes to grout take or probable grout flow patterns.

15. Design. The original design of the dam grout curtain extended 200 feet below the base of the dam which was approximately 130 feet below the base of the high-water loss zone shown on figure 8. The B-holes of the consolidation grouting extended to the base of the high water loss zone in the valley bottom. The

depth of grouting into the right abutment was appreciably extended into the abutment by the change made during construction, i.e. installation of the three grouting and drainage tunnels. The depth of grouting into the left abutment was also appreciable from the tunnels provided with the original contract plans and specifications.

The B-hole grouting on the abutments was accomplished through holes battered into the abutments. The abutment holes had high takes as they intersected many open relief joints. The A-holes had low takes in the zone grouted by the B-holes in the bottom of the valley and the abutments, indicating that the B-hole grouting was effective.

The design of the grout curtain did not extend into the left abutment far enough to intercept the seepage flow that developed when the pool was raised. However, there was no preconstruction geologic information that indicated a need for grouting to this depth in the abutment.

It is concluded that the design as modified during construction was satisfactory although angling of the A-holes into the abutments would have given a better chance to intersect the relief joints than the vertical holes used.

It is noted that the board of consultants in their June 1963 meeting suggested that a drift or drifts be excavated in the high right abutment to more fully explore the stress relief jointing indicated by cores and log of DH-25. The takes in several water tests in DH-25 exceeded the capacity of the pump. This suggestion of the board may have been the reason that the design of the deep grout curtain on the right abutment was changed to include the three grouting and drainage tunnels, although this is not substantiated in the available records.

The board also suggested deepening of the drainage holes. The change in the right abutment grouting also increased the penetration of the drainage curtain into the abutment.

16. Grouting methods and procedures. The specifications established ascending-stage grouting with packers as the basic grouting method, but provisions were included to use descending-stage grouting with packers if directed by the contracting officer. The records indicate that descending-stage grouting was probably used only in the valley bottom where artesian conditions were encountered in several holes.

(a) Specifications. A travel report dated December 11, 1967 by L. R. Gebhart covering a trip to the site on November 15-17, 1967 indicated that the contractor had submitted several drilling and grouting claims, alleging overruns and changed conditions. The specifics on these claims were not available in the review documents; hence, it is not known if the claims were related to the specifications.

It is considered that the specifications should include: (1) minimum capacities for the mixing and grouting equipment; (2) minimum diameter of the grout tube through the packer; (3) a maximum length between the grout supply line from the sump to the header; (4) range of grouting mixes to be used; and (5) provisions for sounding and final backfilling of completed grout holes.

The specifications should prohibit the use of a pigtail as was used on some of the B-holes. The use of a long pigtail defeats the purpose of a circulating line. Grout is in continuous circulation in the line from the header to the sump; however, the grout in a pigtail is not in continous circulation unless the hole is on vacuum, and the cement tends to settle out and build up in the line causing the line to be eventually plugged. Contractors prefer to use the pigtail as only a single line has to be moved when a hole is completed.

(b) Water-pressure tests. It is considered that the specifications should state directly the requirement for a 5-minute water-pressure test for each zone to be grouted. As written the packer must be tested against the water pressure equal to the grouting pressure for 5 minutes, but the time for the water-pressure test with measurement of water takes is not directly stated.

It is considered that the results of the water-pressure tests should be used as a guide in selecting the initial grout mix.

(c) Grout mixes. To reduce shrinkage and bleeding, it is considered that the thickest grout that the hole will accept readily should be used. The use of overly thinned grout can also result in excess travel of the grout beyond the limits of the planned curtain.

A review of the summary of the daily drilling and grouting reports indicates that most A-holes were started and completed with a 7:1 water-cement ratio unless grout leaked to the surface or into tunnels. Many of the B-holes also used relatively thin mixes throughout the grouting even though the hole had a high take. Examples are as follows:

(1) A-hole G-331 (stage depth 25 to 30 feet) accepted a total of 1,048 sacks of cement at a water-cement ratio of 7:1 and at pressures from 130 to 25 psi. The maximum rate of grout consumption was 66 sacks per hour or the equivalent of 57.75 gallons per minute of 7:1 grout. It must be assumed that the hole would accept the same (or more) in gpm of water. If so, the hole could have been started with a thicker mix, i.e. 4:1 or 3:1 and thickened gradually until the hole was taking grout at a reasonably steady rate at the maximum desired pressure.

(2) A-hole G-322 accepted a total of 2,639 sacks of cement at stage depth of 40 to 46 feet at water-cement ratios of 7:1 maximum to 4:1 minimum. Pressures ranged from 100 to 70 psi and the maximum rate of grout consumption was 90 sacks per hour or 78.75 gpm for a 7:1 mix. The reduction in water-cement ratio was probably because grout leaks occurred in the tunnel walls, the canyon wall above the draft tubes and in the powerplant drainage tunnel. The water-pressure tests must have also had high takes and the initial mix could have probably been established thicker than the final mix used.

(3) B-hole on line No. 1, block 16, Station 12+34, accepted 1,744 sacks of cement at stage depth 2 to 17 feet and at water-cement ratios of 5:1 maximum to 4:1 minimum. Injection pressures ranged from 15 psi to 0. The maximum rate of grout consumption was 34 sacks per hour. The inspector recorded grout and water leaks in the foundation tunnel, and water seeps at the

rock surface from 50 to 250 feet downstream of the dam. After having pumped a hundred sacks of cement, the inspector could have reduced the water-cement ratio to reduce leakage and prevent the grout from travelling well beyond the area required for treatment.

In the examples cited above, it is considered that much thicker mixes could have been used in the grouting. If a hole is taking grout at a very fast rate with little or no pressure build-up, the water-cement ratio can be reduced in whole units until pressure starts to build up; thereafter, the mixes should be changed gradually in partial rather than whole units, i.e. 5:1 to 4.75:1 to 4.5:1, etc.

(d) Grout-injection pressures. It is considered that the rules used to establish the maximum permissible pressures are on the unsafe side and that the rules permit pressures higher than needed to move grout for the full width of the dam. The rules are based on the allowable pressures at the gage rather than the pressure at the packer, which also includes the pressure due to the grout in the line between the gage and the packer.

Where open relief joints exist in the abutments in combination with wet seams of clay gouge dipping toward the canyon, as was found at El. 7,090 in the left keyway, extreme care is needed to prevent movement of large rock blocks. Pre-bolting of abutments with open relief joints is a necessary precaution because even under the best geologic investigations it may not be possible to determine that presheared horizontal weak seams in the rock do not exist. Hence, for holes into abutments, even after rockbolting, pressure sufficiently only to move the grout the desired distance should be used. The build-up of a substantial height of fluid grout over a long distance could create enough horizontal force to move a large section of the abutment rock. Although thicker grouts create a higher hydrostatic pressure than thin grouts the thicker grouts set much quicker and do not spread over such a long distance. Hence, thicker grouts are safer to use than thin grouts from a sliding stability standpoint.

A review of the available grouting records indicates that rules for establishing the maximum pressures on this project were followed; however, the need for the maximum pressures used is questioned as per the following examples:

(1) B-hole, line No. 5, block 5, Station 7+80. This hole accepted 228 sacks of cement at a stage depth of 52 to 72 feet (hole was angled 30 degrees from vertical) at pressures ranging from 65 psi to 0. The water-cement ratio was 4:1. The static head pressure of 4:1 grout at a vertical depth of 45 feet is 24 psi. Hence the total pressure at the packer with 65 psi at the gage was 89 psi.

(2) B-hole, line 1, block 2, Station 6+93, rock El. 7,106, pipe angle 30 degrees from vertical. In the stage from 20 to 27 feet the hole had a take of 49 sacks at gage pressures ranging from 35 to 20 psi with water-cement ratios of 7:1 maximum to 5:1 minimum and at a maximum pumping rate of 12 sacks per hour. The maximum pressure at the packer would have been approximately (35+9) 44 psi. The water level in the hole was at a depth of 27 feet. In this same hole at a depth of 50 to 71.5 feet a gage

pressure of 65 psi was used with no grout take. The rock in block 2 was located above the wet seam of clay gouge found at El. 7,070 dipping toward the canyon. Hence the lowest possible pressures to make the grout flow should have been used in blocks 1 and 2 above the gouge seam.

(3) In A-hole G-9-2, which was grouted from the lower foundation gallery, the pressures were increased with depth with all stages below a depth of 165 feet having a gage pressure of 360 psi. The hole had a take of 472 sacks at a depth of 180 to 185 feet using a water-cement ratio of 7:1. The total pressure at the packer was (360+88) 448 psi. With this much take of highly fluid grout the pressure could have spread over a large area of the foundation. Computations of effective pressures as were made for Hungry Horse Dam would indicate that the uplift was excessive.

(d) Spacing of holes and closure. With reference to the takes in the table on page 407 of appendix B, the progressive decrease in unit take from primary through the final closure holes indicates that the voids in the rock were being progressively filled and that the grouting was effective. In the B-hole grouting, considerable split spacing was used to fill the voids in the rock, and a limited amount of split spacing was used in the A-holes. A review of the grouting profiles indicates many places where additional split spacing of the A-holes to 5 feet or less was warranted as several 10-foot spaced holes had large take. At the left end of the grout curtain there were two holes that had high takes in the area where seepage developed later. Hole G-1016 was the end hole grouted from the top of the dam as shown on

Drawing 622-427-1896. It had a take of 368 sacks of cement in the upper 20 feet. At the next level down, hole G-339 was drilled as a "fanned out" hole from the El. 6,965 tunnel. It had a take of 1,862 sacks from a depth of 50 to 55 feet. Although G-340 had been previously grouted with no take, it is not understood why additional "fanned out" holes were not drilled from the end of the tunnel and from the end of the dam as two holes indicated large voids in the rock in this area.

As shown on Drawing 622-427-1897, all four end holes (G-721, G-816, G-913 and G-1109) on the right abutment had large takes without additional holes being drilled and grouted from the ends of the two tunnels. Although no seepage problems have developed on the right abutment, it is considered that ends of the tunnel should have been used to extend the curtain further into the abutment, especially because the end holes indicated appreciable voids in this area.

(e) <u>Refusal criteria</u>. Experience has shown that a hole accepting grout at a rate of one cubic foot of grout mixture or less in 10 minutes at the maximum specified pressure is at practical refusal and the time spent in trying to inject additional grout is of little or no benefit to the owner. If payment to the contractor is based on the number of sacks placed rather than by pumping time, it works a hardship on the contractor to continue pumping the additional time. Unless the owner maintains close inspection, an unscrupulous contractor can, and often does, "kill the hole" by sudden application of high pressure at the grout header or by "accidently" thickening the mix.

(f) Final backfill of holes. It is considered that all completed grout holes should be sounded to determine the level of solid grout fill and that any voids found should be filled by the tremie method with thick grout.

17. Asphalt grouting and extended cement grouting of the left abutment. The asphalt grouting was used in an attempt to reduce the flow in the large water channels. Gebhart[2] states:

> "The amount of leakage into the power plant drainage tunnel was measured as the reservoir filled. To obtain the effectiveness of the asphalt grouting, comparison was made at comparable reservoir elevations as the reservoir surface was lowered during grouting operations. These figures show that asphalt grouting resulted in 65% reduction in total leakage into the drainage tunnel between July 18 and September 9, 1969."

Gebhart also indicated that when the asphalt was encountered in the later cement grout work it was still plastic and that its use for long-term blockage under pressure was questionable.

The cement grout takes in the extended curtain indicate that the original curtain should have been extended into the abutment about 120 feet. The core drilling provided in the specifications could have been used to determine the extent of the voids at the end of the tunnel as indicated by grout holes G-1016 and G-339.

18. Unexpected geologic conditions encountered during grouting. The open water channel found in the extended grouting on the left abutment was unexpected as neither the geologic mapping nor the drill holes extended this far. If DH-36 and DH-37 had been inclined into the abutment (see figure 8) they would have had a better chance of encountering the relief joints and other defects in the abutment.

19. <u>Grout takes as related to geologic conditions</u>. The grout takes at this site were in accordance with the geologic conditions. The site conditions were such that open relief joints should have been expected in the abutments and crushed rock and/or sprung beds should have been expected in the valley bottom. These conditions were confirmed by the surface mapping and by the drill holes. The angle holes in the abutments had several water losses in excess of pump capacity, and the zone of high water loss and high grout takes were in agreement within the areas explored. To illustrate this point the logs of DH-26 (right abutment), DH-14 (valley bottom), and DH-27 (left abutment) are included as figures 11, 12 and 13.

20. <u>Evaluation of grouting and drainage</u>. The main objectives of the grouting and drainage are to control the seepage and uplift within tolerable and safe limits. A secondary purpose of the B-hole grouting is to fill the voids in the rock directly beneath the structure to decrease the foundation movements from the dead and live loads.

The recorded seepage flows for 1980 and 1981 are shown on figure 14, with the total volume ranging from 30 to 55 gpm. According to the SEED report these flows are within tolerable limits. The additional grouting accomplished in 1969 and 1970 was particularly effective in reducing the seepage flows into the powerplant drainage tunnel. Without effective grouting of the relief joints in the abutments and the fractured rock in the valley bottom, seepage at this site would have been excessive. The SEED inspection of 25-27 April 1978 found fines adjacent to

GEOLOGIC LOG OF DRILL HOLE

FEATURE Morrow Point Dam[illegible] PROJECT Curecanti STATE Colorado

HOLE NO. DH 26 [illegible] LOCATION [illegible] COORDINATES N.656,611; E.1,416,570 GROUND ELEVATION 7017.0 ANGLE FROM HORIZONTAL -29°

BEGUN [illegible] FINISHED [illegible] DEPTH OF OVERBURDEN 0 TOTAL DEPTH 100 BEARING OF ANGLE HOLE N.27°W

DEPTH AND ELEV. OF WATER TABLE [illegible] (5-25-62) HOLE LOGGED BY H. B. Bennett FOREMAN C. Hopkin

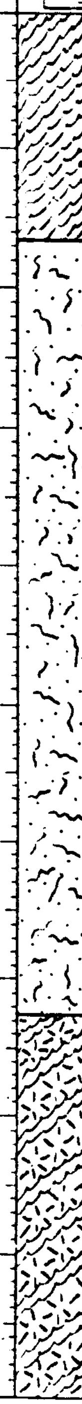
NOTES: Lost drill water at 30.6

Nx Cs 0–[illegible]; Nx D to 100

Core recovery: 100%

Depth From	Depth To	Loss (GPM)	Pressure (P.S.I.)	Time (Min.)
P10	20	18	100	5
P20	30.6	11	100	5
P30.6	40.3 (pump capacity)	18	50	5
P40.3	49.6 (pump capacity)	18	50	5
P46.8	56.8 (pump capacity)	16	25	5
P56.8	69.8 (pump capacity)	19	25	5
P69.5	80 (pump capacity)	18	40	5
P80	90 (pump capacity)	18	40	5
P90	100	0	100	5

Elevations: 7017.0; 7000.9; 6961.8; 6966.5



CLASSIFICATION AND PHYSICAL CONDITION

0-16.7 BIOTITE SCHIST. Quartz pegmatite 0.2-1[illegible]. Broken to gravel sizes and 0" [illegible]-4.5. Weathered and stained. 50% mica. Breaks with fingers along edges in places to a medium hammer blow in others. Brecciated 3.5-4.5. Jointed every 2" to 6". 30° schistose planes.

16.7-72.7 MICACEOUS QUARTZITE. Breaks with medium hammer blow. Stained on most breaks. Breaks parallel with the alignment of the mica, 42° to core axis. Irregular jointing. 25% mica.

72.7-100.0 AUGEN GNEISS. Biotite schist with eyen structure. Breaks with hard hammer blow. 25° schistose planes. 90% mica. Less jointing and staining. PEGMATITE stringers. One thin quartzite layer. Granite porphyry at 87.2.

Core generally in good condition and medium hard.

T. D. 100' Required Depth

EXPLANATION

CORE LOSS

CORE RECOVERY

Type of hole .... D=Diamond, H=Haystellite, S=Shot, C=Churn

Hole sealed .... P=Packer, Cm=Cemented, Cs=Bottom of casing

Approximate size of hole (X series) Ex = $1\frac{1}{2}$", Ax = $1\frac{7}{8}$", Bx = $2\frac{3}{8}$", Nx = 3"

Approximate size of core (X-series) Ex = $\frac{7}{8}$", Ax = $1\frac{1}{8}$", Bx = $1\frac{5}{8}$", Nx = $2\frac{1}{8}$"

Outside diameter of casing (X-series) Ex = $1\frac{13}{16}$", Ax = $2\frac{1}{4}$", Bx = $2\frac{7}{8}$", Nx = $3\frac{1}{2}$"

Inside diameter of casing (X-series) Ex = $1\frac{1}{2}$", Ax = $1\frac{29}{32}$", Bx = $2\frac{3}{8}$", Nx = 3"

-29°

ANGLE HOLE ☒

VERTICAL HOLE ☐

HOLE DH 26

FIGURE 11

BUREAU OF RECLAMATION

GEOLOGIC LOG OF DRILL HOLE

FEATURE Morrow Point Damsite PROJECT Curecanti STATE Colorado

HOLE NO. DH 14 LOCATION Dam Axis, left of river GROUND ELEVATION 6768.2 ANGLE FROM VERTICAL 0°

COORDINATES N.655,310; E.1 416,545

BEGUN 11-20-61 FINISHED 11-22-61 DEPTH OF OVERBURDEN 22.3 TOTAL DEPTH 122.8 BEARING OF ANGLE HOLE

DEPTH OR ELEV. OF WATER TABLE See below HOLE LOGGED BY N.B. Bennett FOREMAN O. Hopkins

NOTES (On water return, water levels, character of drilling, etc.)

- 40% to 80% water return 0-54.5'
- Nx Cs
- Blasted boulder 17' to 18.6'
- No water return 54.4-122.8
- Nx D

Type of hole / Core recovery (%): WS, WS, WS (0–22.3); 100; 98; 100; 100

PERCOLATION TESTS

Depth (ft) From	To	Loss (g.p.m.)	Press. (p.s.i.)	Length of test (min)
P26.5	36.5	Water leaked around packer		
P33	43	8	50	5
P33	43	12	100	5
P42.3	56.3	17	50	5
P42.3	56.3	22	80	5
P56	69	16.4	50	5
P55	69	20.4	85	5
P76	86	12	50	5
P75	86	17	100	5
P86	96	0	50	5
P86	96	3.2	100	5
P96	106	0	50	5
P96	106	2.4	100	5
P105.8	122.8	0	50	5
P105.8	122.8	0	100	5

Elevations: 6768.2, 6745.7, 6738.7, 6732.2, 6725.2, 6711.1, 6690.5, 6687.9, 6675.5, [illegible], 6645.4

LOG

CLASSIFICATION AND PHYSICAL CONDITION

0-22.3 SAND, GRAVEL, COBBLES, and a few BOULDERS. Black. Angular to rounded. Talus and river-fill.

22.3 Bedrock

22.3-29.5 BIOTITE-SCHIST. Breaks with medium hammer blow. Top 2' is weathered and stained, and broken to cobble and boulder size. No joints 24.3-29.5

29.5-36 MICACEOUS QUARTZITE. Hard. 1 weathered joint. Other breaks are fresh. Average size = 1'.

36'-43' BIOTITE-SCHIST. Soft. Quartz 39.5 to 40'. Broken surfaces weathered and stained. No open joints. Average size=15". Occasional quartz healed joint.

43-57.1 QUARTZITE, MICACEOUS. Breaks with hard hammer blow. 2 joints 15° to core axis 50-50.8 (rock broken along joint surface) & 51.5 to 52.1. Both surfaces weathered & stained. 2 other joints. More mica 52-54'.

57.1-77.7 QUARTZ. White to pink. Occasional biotite flakes. No joints. Hard but brittle (breaks with easy hammer blow). Broken to cobble size 64.7-65 and 69-69.3'. Other sizes to 21". Few weathered surfaces.

77.7-80.3 BIOTITE-SCHIST. Breaks with fingers. Weathered.

80.3-92.7 QUARTZITE, MICACEOUS. Breaks with medium hammer blow. Joints parallel to core axis 80.4-81.4 and 83.1 to 84.5. Rock broken along joint surfaces, with weathering and staining. Other breaks are fresh. Occasional quartz seam.

92.7-102.3 QUARTZ. Occasional BIOTITE flakes. Hard but brittle. Mostly cobble sizes. Maximum size = 9". Broken surfaces all stained.

102.3-122.8 [illegible] (gneiss with [illegible] eyed structure) Breaks with easy hammer blow along foliation. Broken to 3" pieces to 105'. No joints. Average size 10" from 105' to bottom. Occasional quartz seam. Biotite mica with large crystals of quartz and feldspar ([illegible] dia)

T.D. 122.8' Required depth

Rock generally soft to hard, mostly in good condition and relatively free of joints.

Water Table

Level	Date
2.5	11-17
3.4	11-18
5.1	11-20
5.1	11-21
5.1	11-22

Hole No. DH 14

FIGURE 12

GEOLOGIC LOG OF DRILL HOLE

FEATURE Morrow Point Damsite PROJECT Curecanti STATE Colorado

HOLE NO. DH27 LOCATION Dam axis, left abutment COORDINATES N.456,202; E1,416,472 GROUND ELEVATION [illegible] ANGLE FROM HORIZONTAL −57°

BEGUN 6-18-62 FINISHED 6-20-62 DEPTH OF OVERBURDEN 0 TOTAL DEPTH 100.7' BEARING OF ANGLE HOLE S.67°W

DEPTH OR ELEV. OF WATER TABLE Dry(6-19-62) HOLE LOGGED BY N.B.Bennett FOREMAN O. Hopkin

NOTES (on water tests, water levels, water return, character of drilling, etc.)

Hole caved in 10-15'.

Water tests at 5-15' and 15-26.4' forced water out of surrounding surface cracks.

Lost drill water at 36'.

TYPE OF HOLE: Nx Cs (0–4); Nx D (to 100.7)

Core recovery (%)
98%
70%
95%
100%
95%
100%
95%
100%
67%
100%

PERCOLATION TESTS

From (ft.)	To	Loss in G.P.M.	Pressure (P.S.I.)	Time of test (min.)
P5	15	14 (pump capacity)	40	5
P15	26.4	16.5	100	5
P26.4	36.7	16.5 (pump capacity)	40	5
P36.9	46.9	17 (pump capacity)	40	5
P45.8	55.8	17 (pump capacity)	40	5
P55.7	87.5	19 (pump capacity)	65	5
P67.5	76.8	15	100	5
P76.8	87.4	9.5	100	5
P87.4	100.7	15	100	5

ELEVATION: 7078.6 (at 24.7); 7033.2 (at bottom)

CLASSIFICATION AND PHYSICAL CONDITION

0-24.7 <u>Augen Gneiss</u> Predominately biotite schist with eyed structur. Breaks with easy to medium hammer blow. Badly broken. 2" average size, 15" maximum size. Silt found on all cracks. Granite pegmatite stringers. 25° schistose planes and foliate planes. 90% mica. Weathered and stained. Irregular jointing.

24.7-100.7 <u>Micaceous quartzite</u>. Breaks with hard hammer blow at which time it breaks into several pieces. Granite pegmatite stringers. Minor jointing. Breaks 80° to core axis. Pegmatite at 54.6 breaks with fingers along edges. Large (1½ to 1½") eyes of mica 46.4-52.6. The rock is also lighter in weight. Occasion- 3" layer of biotite schist. Pieces to 30" min length.

Core generally in poor condition 0-24.7 and soft. Hard and good condition 24.7-100.7.

T.D. 100.7 Required depth

EXPLANATION

CORE LOSS

CORE RECOVERY

Type of hole	D=Diamond, H=Haystellite, S=Shot, C=Churn
Hole sealed	P=Packer, Cm=Cemented, Cs=Bottom of casing
Approximate size of hole (X-series)	Ex = $1\frac{1}{2}$", Ax = $1\frac{7}{8}$", Bx = $2\frac{3}{8}$", Nx = 3"
Approximate size of core (X series)	Ex = $\frac{7}{8}$", Ax = $1\frac{1}{8}$", Bx = $1\frac{5}{8}$", Nx = $2\frac{1}{8}$"
Outside diameter of casing (X-series)	Ex = $1\frac{13}{16}$", Ax = $2\frac{1}{4}$", Bx = $2\frac{7}{8}$", Nx = $3\frac{1}{2}$"
Inside diameter of casing (X-series)	Ex = $1\frac{1}{2}$", Ax = $1\frac{29}{32}$", Bx = $2\frac{3}{8}$", Nx = 3"

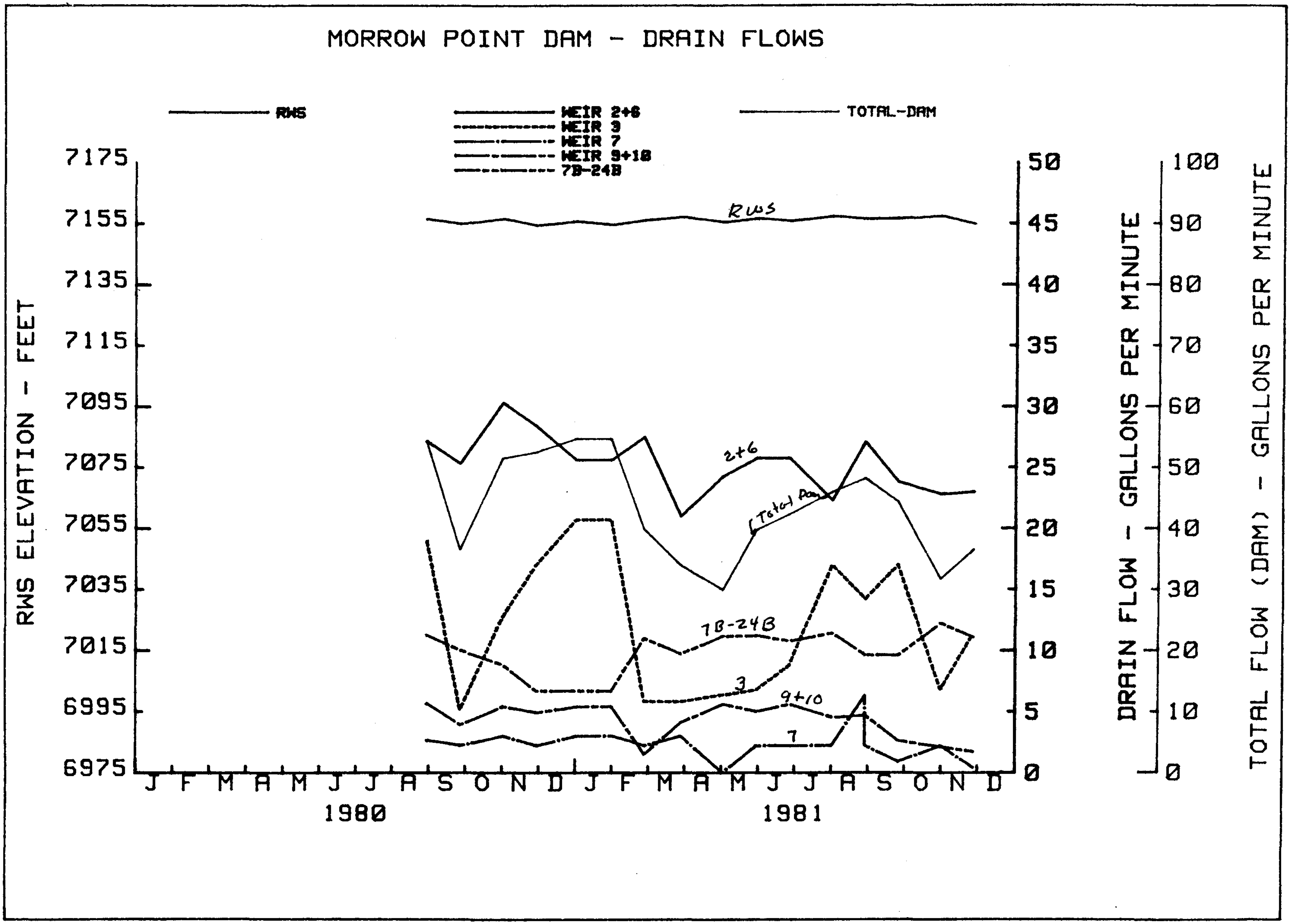
ANGLE HOLE ☒

VERTICAL HOLE ☐

7 boxes of core.

Hole No. DH-27

FIGURE 13



ENGINEERING & RESEARCH CENTER - STRUCTURAL BEHAVIOR SECTION

FIGURE 14

Header file 4MRDRA

the weir in the powerplant drainage tunnel. It was believed that these fines were piping from shear zone A. The investigations of this situation since the SEED report of February 26, 1979, are not reported.

There are no instruments to measure the uplift on the base of the dam or to measure the hydrostatic pressures in the joints and bedding planes of the supporting rock beneath and immediately downstream of the dam. It can be postulated that the extensive grouting and drainage has greatly reduced the uplift and hydrostatic pressures, but a positive evaluation of the pressures cannot be made without instrumentation.

With regard to the effectiveness of the B-hole grouting in consolidating the foundation, the draft SEED report indicates the movement of the dam was more than predicted during initial loading. This was attributed to closing of joints in the left abutment. Comparison of movements after initial deformation indicated the dam was behaving elastically, as predicted. A review of the B-hole grouting on the left abutment indicates that the holes were drilled on relatively close centers with moderate grout takes. Any unfilled joints encountered by the B-holes or by the A-holes would have been filled with grout. However, as most joints are partly filled with weathered rock and soil, the cement grout could not be expected to displace or fill the voids in these materials. The best method to prevent excessive foundation deflection is to remove all weathered rock and to remove the unweathered rock as far as possible until the joints are tight.

As the foundation movements were evidently within tolerable limits, it must be concluded that the foundation excavation and grouting were adequate.

VI. RECOMMENDATIONS

21. Morrow Point Dam.

(1) Piezometers be installed in the bedrock immediately downstream of the dam as there may be high hydrostatic pressures in the rock joints even though no seepage is occurring.

(2) Pipes be installed between selected drain holes in the El. 6,725 foundation gallery to determine the uplift pressures at the base of the dam.

(3) For Phase II investigations core holes be located to intercept areas of high grout takes in the foundation and abutments to determine if the grout has deteriorated.

22. Other large concrete dams.

(1) The preconstruction geologic investigations be expanded to include an analysis of the geologic conditions in regard to the design of the grouting and drainage programs.

(2) Geologic mapping and angled core drilling in the preconstruction stage be extended into abutments with relief joints until no evidence of the joints is found.

(3) Specifications contain minimum requirements on the capacity of mixing and grouting equipment, minimum diameter of grout tube through packer, and method of sounding and final backfilling of grout holes.

(4) Consideration be given to use of angled grout and drain holes in foundation and drainage tunnels located in abutments with vertical relief joints.

(5) Higher order splits be drilled and grouted on both sides of holes having high grout takes until the curtain is tight.

(6) Grouting and explorations be made from the ends of grouting and drainage tunnels to determine if the grouting has been extended a sufficient depth into the abutments.

(7) Results of water-pressure tests be used as a guide in starting the hole with as thick a mix as practical and that the mix be progressively thickened in accordance with the rate of take and pressures encountered.

(8) Safe grout injection pressures be determined by the site geologist and engineers for the packer settings in various reaches of the dam based on effective pressures at the packer with appropriate consideration given to the topographic and geologic conditions.

(9) Rock bolting be installed on all abutments with relief joints prior to grouting.

(10) Grouting program be continuously reviewed by site geologist and engineer to determine if changes should be made in the drilling and grouting and to determine if explorations are needed.

APPENDIX

APPENDIX A

REFERENCES

1. "Morrow Point Dam and Powerplant Foundation Investigations", A Water Resources Technical Publication, Bureau of Reclamation, Denver, October 1965.

2. Gebhart, Lloyd R., "Experimental Cationic Asphalt Emulsion Grouting", Journal of Soil Mechanics and Foundation Division ASCE, Vol. 98 No. SM 9, Proc. paper 9172, Sept. 1972, pp. 859-868.

3. Report No. G-185, "Preconstruction Geologic Report: Morrow Point Dam, Powerplant and Reservoir Sites--Curecanti Unit--Colorado River Storage Project", by Lloyd Calder, Salt Lake City, Utah, Dec. 1962.

APPENDIX B

Foundation Grouting, Drilling and Drainage

Introduction

The foundation rock beneath Morrow Point Dam and adjacent areas was drilled and grouted and foundation drainage was provided by holes drilled into the rock. The general plan followed in pressure grouting the rock foundation is outlined below:

(a) Drilling and grouting the rock foundation of the dam with low-pressure shallow (B-hole) grout holes, followed by high-pressure deep curtain (A-hole) grout holes.

(b) Drilling and grouting the rock under the spillway stilling basin and weir.

(c) Drilling and grouting that part of the rock surrounding the penstock intake structure and penstock tunnels immediately behind the penstock intake structure.

(d) Grouting the backfill concrete placed in exploration tunnels.

(e) Placing grout by the grouting method to complete the placement of concrete in tunnels.

(f) Drilling and/or grouting as required, for permanent closure of the diversion structure.

(g) Drilling and grouting at other locations as directed.

Foundation drainage of the dam and powerplant was provided by drilling holes into the rock through 3-inch-diameter pipes embedded in concrete in the dam foundation gallery and tunnels or drilling directly into the rock on up-drain holes. All the drilling and grouting was performed by Continental Drilling Company of Los Angeles, California, subcontractors of the prime contractor.

The first grouting of the project began in April 1964 when backfill grouting of the diversion tunnel was started. The foundation grouting was completed in January 1968. No drilling or grouting was performed during the periods from May 1964 through July 1965 and during the winter months of 1965-1966 and 1966-1967. Drawing Nos. 622-D-1056, 622-D-1057, 622-D-1494 and 622-D-1800 show the general plan for foundation drainage.

Drilling and Grouting Equipment:

All of the "B" hole and "A" hole drilling was performed with Chicago pneumatic No. 55 drills. Chicago pneumatic No. 65 drills were used for drilling all down (NX) holes and the shallower NX up drain holes and Chicago pneumatic No. 8 drills were used for drilling the deeper NX up drain holes. All drilling was accomplished with diamond bits. Both plug and core bits were used for drilling 1½-inch (EX) grout holes. Only core bits were used for drilling the 3-inch-diameter (NX) drain holes.

Portable grout plants were set up at various locations for the different phases of the work. Various sizes of Gardner-Denver or Worthington duplex piston-type grout pumps were used, depending upon the required pumping pressures. A grout plant consisted of a pump mixing tub and agitator tub in series, each tub having a capacity of 18 cubic feet and equipped with air-driven agitator. Grouting was performed with a gauge equipped header using circulating lines, through 1-inch-diameter flush-joint packer pipe and leather cup packers. Field telephones provided communication between the various components of grouting activity. See Photograph Nos. P622B-427-3098NA, P622B-427-3100NA and P622B-427-8033NA, and P622B-427-8560NA.

Consolidation Grouting

B-Holes Dam Foundation:

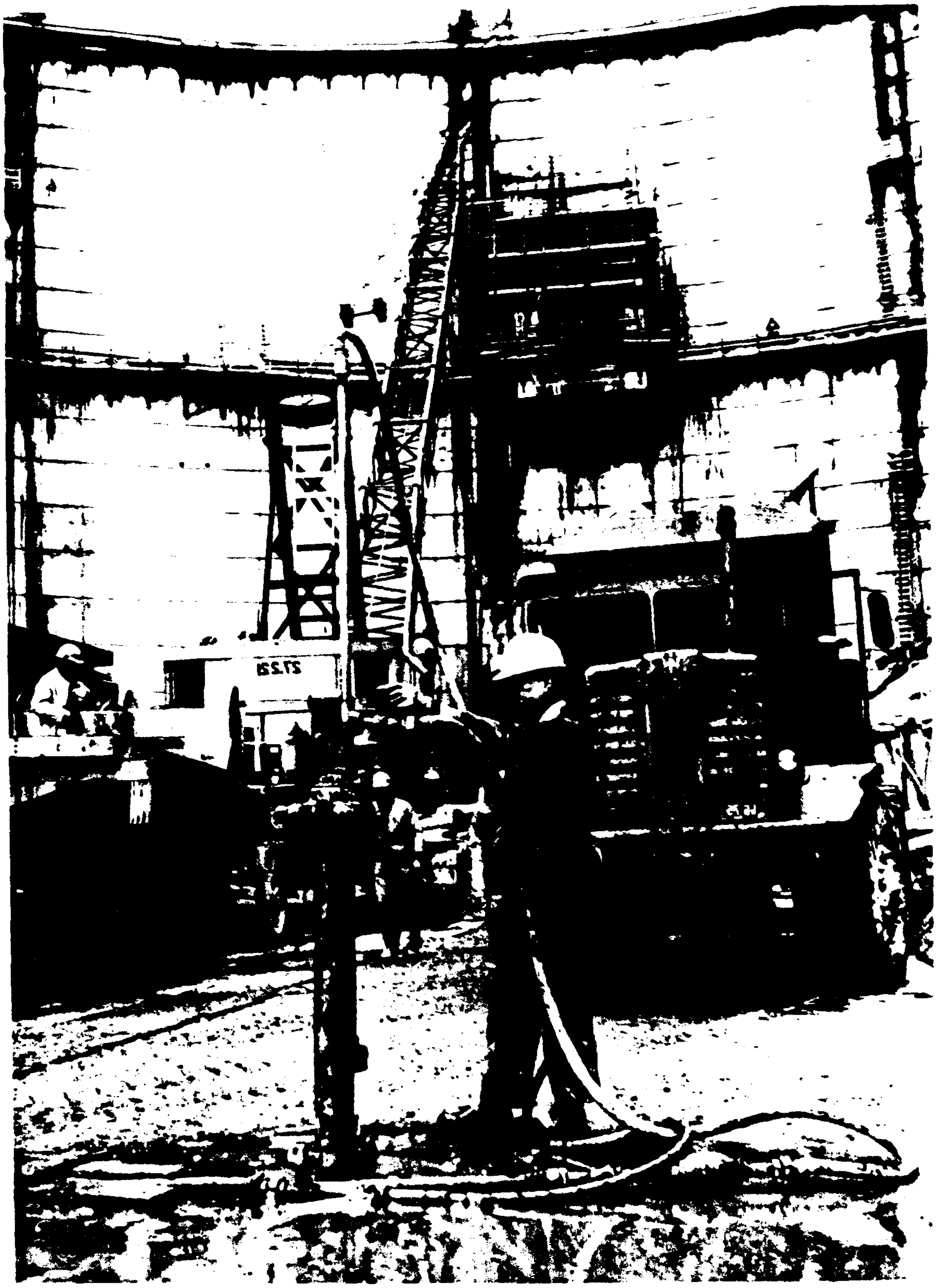
Initially the B-hole foundation grouting program in the river bottom was to consist of 4 lines of holes, maximum 70 feet deep, 20 feet apart, paralleling the upstream face of the dam. The lines were spaced 20 feet apart except for the two upstream lines which were 10 feet apart. After excavation of the foundation had been completed, the joint systems had not tightened as anticipated and artesian water flows from drilled grout holes indicated that a more extensive consolidation grouting program would be required.

The B-hole grouting program was initiated on August 2, 1965, and continued through November 24, 1967, when work was shutdown for the winter. Most of the grouting in Blocks 7 through 13 and Block 1 was accomplished directly from nipples anchored in the rock surface, except for a few shallow holes in Blocks 7, 9, 11 and a portion of Block 13 where supplemental grouting was accomplished through riser pipes extended through one or more concrete lifts. These pipes were set in the rock in areas where surface leaks were very extensive and it was felt that a more satisfactory job of consolidation could be attained. All holes above El. 6755 were grouted from pipes extended through the concrete after one or more lifts had been placed. Photograph No. P622B-427-3661NA shows pipe nipples installed in the rock in the Block 1 area.

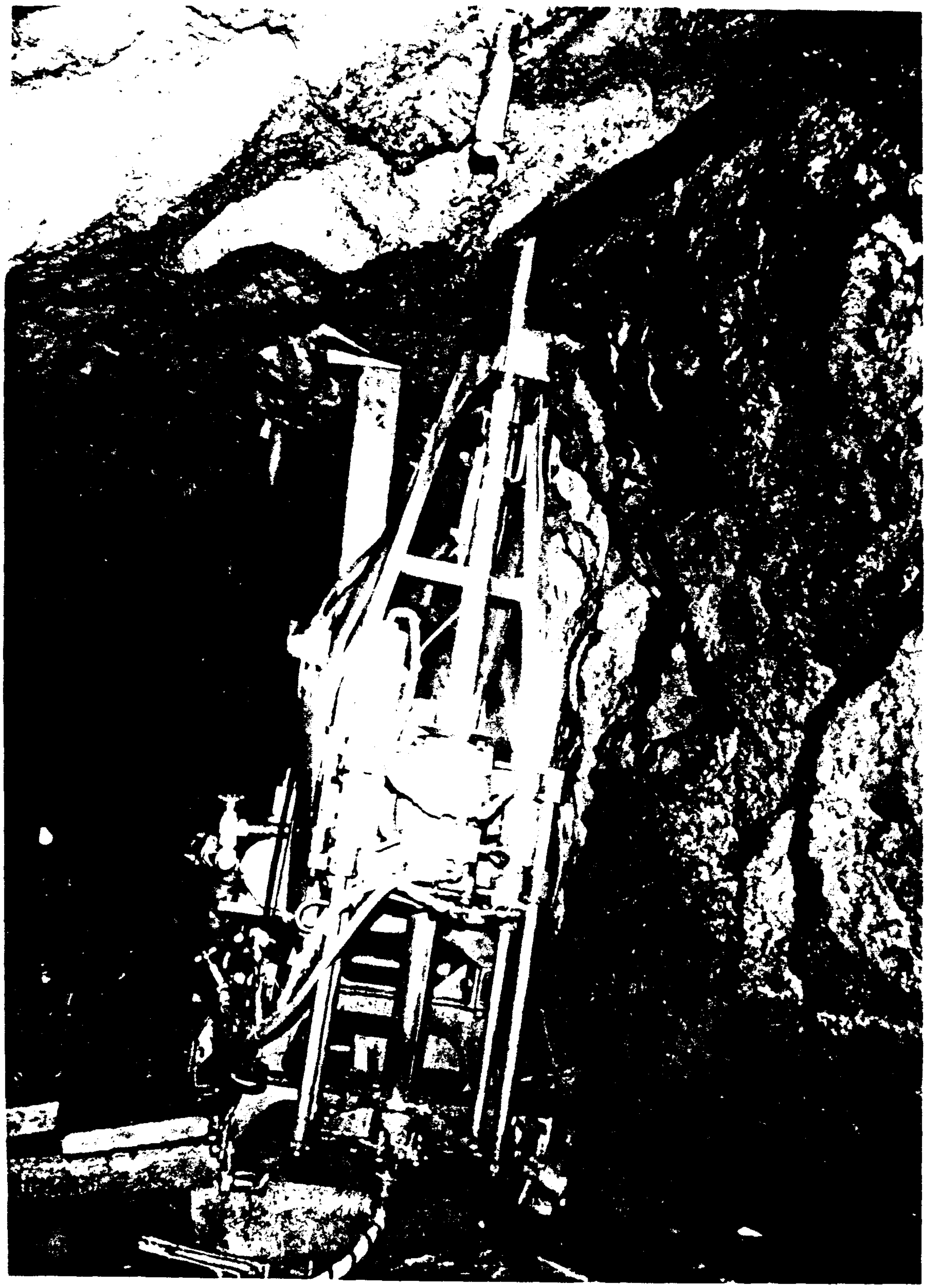
Holes in the river bottom were drilled to intersect cracks and shear planes at angles varying from vertical to 30 degrees from vertical.

P622B-427-3098--Curecanti Unit - Morrow Point Dam, Colorado
Grout plant located downstream from toe station 9+80 (approx.).
Upper pair of tanks are the mixing tanks. Lower pair of tanks
are agitating tanks. Johnson-MK, Spec. No. DC-5915. 8-18-65

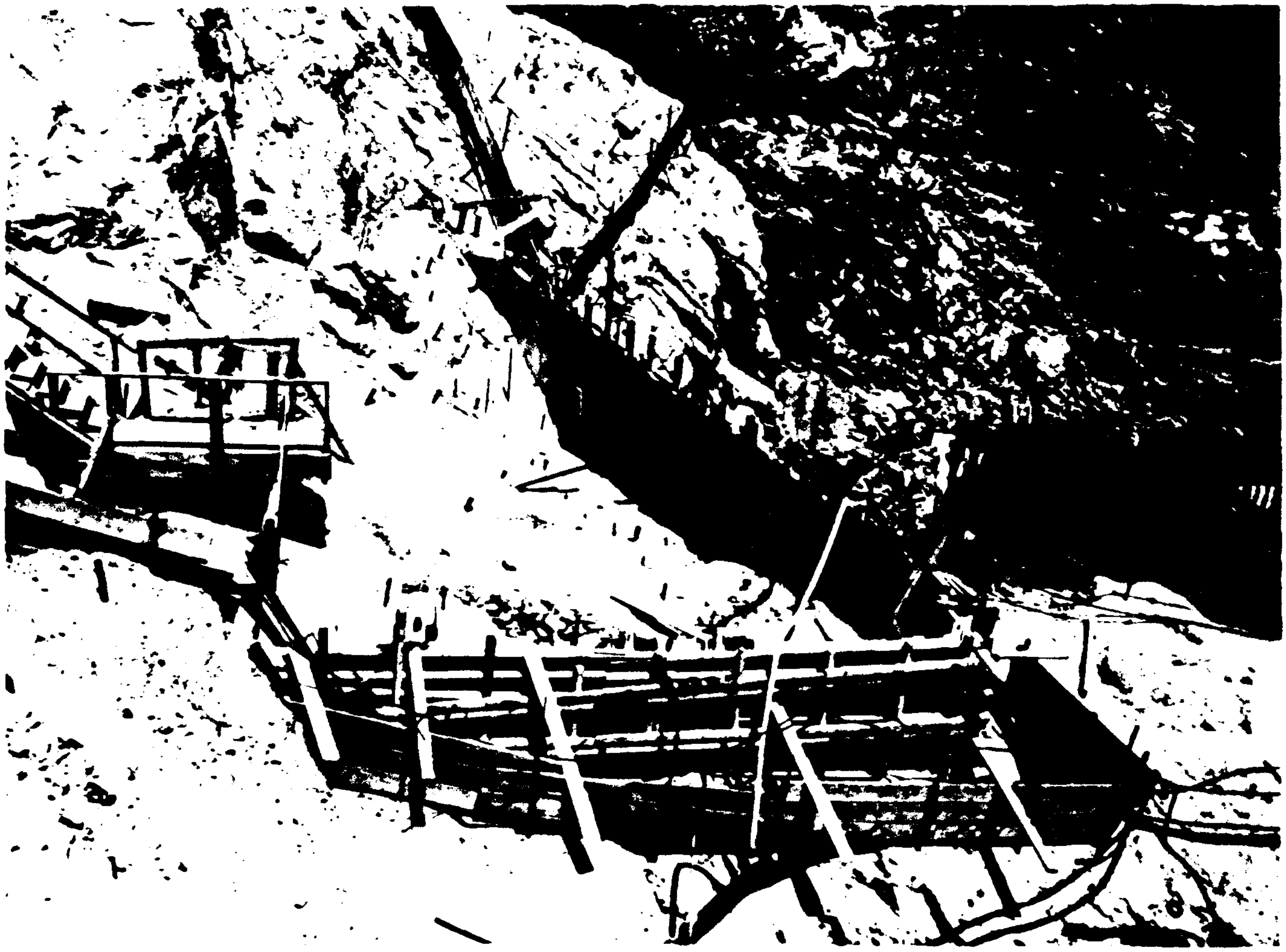
P622B-427-3100 NA--Curecanti Unit - Morrow Point Dam - Colorado--
Typical grouting manifold. Hole is being grouted from nipple.
Johnson-MK, Specification No. DC-5915. 8-18-65



P622B-427-8033 NA-- Curecanti Unit - Morrow Point Dam, Colorado--
View shows a CP drill set up and drilling at Sta. 1+35, 10 feet left of the plane of centers in the stilling basin. Holes in this area are drilled and grouted through previously placed nipples in the stilling basin slab. 4-12-67



P622B-427-8560 NA--Curecanti Unit - Morrow Point Dam - Colorado--
Foundation Tunnels: CP-8 drill drilling up-holes in elevation 6965
foundation tunnel on the left abutment. 2-28-68



P622B-427-3661 NA--Curecanti Unit - Morrow Point Dam - Colorado--
Dam: View of the Block 1 foundation rock. The forms have been built to Elev. 7137.5. The form near the center is on the Block 1-2 line. Johnson-MK, Spec. No. DC-5915. 8-10-66

Considerable difficulty was experienced in grouting these holes because of excessive leakage at the surface. The grout traveled through the cracks in the rock for considerable distances from the hole being grouted. Irregular jointing was also quite apparent at depths up to 50 feet as several holes leaked grout at the surface from stages at this depth. Due to a moderate grout acceptance at depth it was decided to drill some holes deeper than 70 feet to insure foundation qualities.

As grouting progressed up the abutments a small number of additional holes were drilled beyond the 70 foot maximum depth as specified. Some were drilled to act as a grout curtain upstream of the foundation tunnels and others were drilled when large grout takes occurred near the bottom of a standard 70 foot hole.

Although leaks in the river bottom area were extensive and covered large areas, leaks on the abutments were usually of the local type and not serious, with exception of several holes on the left abutment where leakage occurred in the canyon wall downstream from the dam in the vicinity above the draft tube outlets. See Photograph No. P622B-427-3698NA. These holes usually had large grout takes and grout leakage which was assessed as moderate. Caulking of these leaks was impractical and unsafe due to jointing and the presence of thin slabs paralleling the canyon walls. Extreme care was taken in controlling pressure in this area.

All grouting of B-holes was performed using leather cup packers in conjunction with flush-joint packer pipe. Grout mixtures varied from a 5:1 to a 1:1 water-cement ratio, with most of the grout being 5:1. Pressures for B-hole grouting were limited to 15 psi at the collar of the hole and increased one psi per foot depth of hole to the packer. A total of 762 holes and 34,474 lineal feet of rock drilled accepted 31,193 sacks of cement grout for an average take of 0.91 sack of cement per lineal foot of hole. The layout and grouting results are shown on Drawing Nos. 622-427-1570, -1635, -1636, -1674, -1675, -1703, -1704, -1717, -1718, -1719, -1847 and -1849.

B-Holes Stilling Basin Foundation:

The B-hole grouting program specified for the stilling basin foundation rock consisted of a pattern of holes 20 feet apart on lines perpendicular to centerline and staggered on 20-foot centers extending from the toe of the dam to the toe of the weir which is 350 feet downstream from the dam. The lines were to extend to El. 6780 on each canyon wall. Holes were to be 70 feet deep in the area of the river bottom and were gradually decreased to a depth of 50 feet on the near vertical canyon walls. Later this pattern was somewhat modified since several areas of the canyon wall were overhanging and determined unsafe to grout using the normal procedure.

P622B-427-3698 NA--Curecanti Unit - Morrow Point Dam - Colorado--
View of the powerplant open cut area above the downstream portal of draft tube No. 1. Grout which leaked out above draft tube No. 1 during the foudation grouting of Block 4 at Elev. 6956± can be seen in the right center of the picture. Johnson-MK, Spec. DC-5915. 8-31-66

Consequently a pattern consisting of a fan and horizontal holes was designed for grouting the near vertical sections of the canyon walls.

The B-hole grouting program for the stilling basin was initiated in February 1967 and continued through August 1967. Most of the grouting was accomplished through nipples set directly in the rock. However, those holes in the near vertical canyon wall section on the right abutment of the weir were grouted through pipe embedded in the concrete. Grouting was accomplished by the closure method, the initial holes being on 40 foot centers, starting in the canyon bottom and progressing upward. All horizontal holes placed in the near vertical sections were drilled after all other grouting in the stilling basin had been completed. Grouting of these horizontal holes then progressed upwards from the lowest horizontal holes with the upper holes acting as vents, which were then grouted progressively as they carried a grout return. Pressure for these horizontal holes was limited to 10 psi at the collar of the holes and increased one-half psi per foot depth of hole to the packer. The use of a long pigtail between the grout header and the grout hole was used so that grouting personnel would be in a safer position during grouting operations. Pressures for all other holes were similar to those used in the dam foundation B-holes.

Surface leaks were extensive over most of the stilling basin area and considerable time was spent in caulking these leaks by the contractor in order to seal the foundation rock properly. Grout mixtures varied from a 7:1 to 1:1 water-cement ratio, with most of the grout being 7:1. Breakdown of the grout take is shown in the following table. The layout and grouting results are shown on Drawing Nos. 622-427-1805, -1806, -1815, -1816, -1817, -1818, -1819, -1820,-1838, -1841, -1842, -1843, -1844, -1845 and -1846 which are included in the Appendix and the following table:

	No.of	Drilling	Take	
Location	Holes	Lin.Ft.	No. Sacks	Sacks per foot
Weir	73	4,437	5,433	1.22
Original Lines	161	9,940	7,759	0.78
Closure Lines	160	9,282	3,513	0.38
Closure Holes between original and closure lines	69	3,661	653	0.18
Subtotal	463	27,320	17,358	0.63
		(Horizontal Holes)		
	51	1,571	1,182	0.75
Grand Total	514	28,890	18,540	0.64

A-Holes - Curtain Grouting:

Drilling of the first deep curtain cutoff holes from the foundation gallery was initiated in May 1967. A-hole drilling and grouting was performed continually in conjunction with other drilling and grouting until January 1968.

Drawing Nos. 622-D-1054, -1055 and -1493 illustrate the general layout of the grout hole pattern. This pattern was generally pursued, with the exception of an additional fan on the end of the left abutment foundation tunnels at El. 6965 and El. 6785. A few of the holes in the foundation gallery were deepened when grout takes occurred in the bottom stages of holes drilled to the specified depth.

Grout mixtures used for the A-hole grouting varied from 7:1 to 1:1 water-cement ratio by volume with most of the grout pumped being 7:1 water-cement ratio. Pressure of 75 psi at the collar with a gradual increase of up to 500 psi depending upon depth of hole was used.

Grout leaks throughout the A-hole grouting program were minimal. A few leaks occurred in the foundation tunnels adjacent to holes being grouted. No grout leaks occurred on the left canyon wall where leaks from B-hole grouting were dominate.

A total of 343 A-holes were drilled from the dam foundation gallery, tunnels and intake structure through 34,562 feet of rock and concrete. These holes accepted 25,092 sacks of cement for an average take of 0.76 sacks per lineal foot of hole. The average grout take in the foundation rock would be slightly higher than the above figure by considering only the total depth of rock drilled and neglecting the footage through concrete. Also grout takes around the periphery of the dam that previously had been grouted by B-holes were negligible . The layout and grouting results of A-hole grouting are shown on Drawing Nos. 622-427-1624, -1625,-1896, and -1897 and the following table:

Location	No. of Holes	Drilling Lin. Ft.	Take	
			No. Sacks	Sacks per foot
Dam Foundation Holes below El. 6785	36	7,565	2,902	0.38
Dam Foundation Tunnels Left Abutment	177	16,700	14,492	0.87
Dam Foundation Tunnels Right Abutment	115	9,462	7,100	0.75
Intake Structure	14	835	598	0.72
Total	342	34,562	25,092	0.76

Closure Take

	Drilling Lin. Ft.	Take No. Sacks	Take Sacks per foot
Original Holes	5,580	11,061	1.98
First Closure Holes	5,296	5,578	1.05
Semi Closure Holes	9,420	7,947	0.84
Final Closure Holes	14,267	506	0.04
Total	34,562	25,092	0.76

B-Holes - Penstock Intake Structure:

B-hole grouting in the penstock intake structure area consisted of vertical holes in the rock foundation beneath the intake structure and trashrack apron; radial holes in the penstock tunnels immediately behind the penstock intake structure; and near horizontal holes paralleling the penstocks behind the intake structure. Photograph No. P622B-427-3977NA shows the area prior to placement of concrete.

The vertical holes were drilled and grouted during March and April 1967 through pipes embedded directly in the rock prior to concrete placement. Initially 70 foot holes were placed 20 feet apart in order to cover the area adequately. However, during the grouting process several holes accepted grout in the 50-70 foot stage and consequently were deepened to a maximum of 90 feet. A total of 485 sacks of cement-grout was injected into 21 holes which were drilled a total of 1,345 lineal feet for an average take of 0.36 sack per lineal foot of hole. Most of the grout pumped consisted of a 5:1 water-cement ratio by volume. Results of grouting these vertical holes are shown on Drawing No. 622-427-1814.

Radial hole grouting of the penstock tunnels immediately behind the penstock intake structure was performed during April 1967. The layout of these holes is shown on Drawing No. 622-D-446.

The four grout rings in each penstock tunnel with six radial holes, each 12 to 30 feet deep, took 619 sacks in 1,190 lineal feet for an average take of 0.52 sack of cement per lineal foot of hole. All of the grout pumped consisted of 5:1 water-cement ratio by volume. Maximum pumping pressure for these holes was 60 psi and results are shown on Drawing No. 622-427-1848.

The near horizontal holes paralleling the penstock tunnels immediately behind the penstock intake structure are shown on Drawing No. 622-D-1811. These holes were all drilled by installing 3-inch-diameter nipples in the rock face and drilling the holes from the top of the concrete placements. After drilling a row of holes $1\frac{1}{2}$-inches in

P622B-427-3977 NA--Curecanti Unit - Morrow Point Dam - Colorado
Penstock: View of the upstream portal of the penstocks. The areas for the Intake Structure base slabs has been excavated and are being cleaned up. Bulkheads for winter protection are visible in both penstock tunnels. Johnson--M.K., Spec. No. DC-5915. 3-8-67

diameter, thin wall pipe was installed from the hole to the nearest concrete form surface and embedded.

Grouting of these holes was not initiated until all holes had been drilled and all concrete in the intake structure had been placed. Grouting was initiated on October 4, 1967 and completed on October 13, 1967. One hundred and three holes were hooked and the remaining 47 holes leaked grout from other holes and were valved or capped. Grouting was started on the bottom row of holes with the row immediately above acting as vents, some of which were hooked as grouting progressed. Surface leaks were concentrated on the left side of the intake structure above the fillet at El. 7130 to El. 7137. A total of 2,763 sacks of cement grout ranging from 5:1 to 1:1 water-cement ratio by volume was injected into 3,778 lineal feet of hole for an average take of 0.76 sack of cement per lineal foot of hole. Pressure for all holes was 25 psi. For layout and grouting results of the horizontal holes see Drawing Nos. 622-427-1900 and 622-427-1901.

Penstock Liner Backfill

Backfill grouting of the horizontal sections of the two penstock liners at both intake and outlet ends to complete the placement of concrete was performed in January and March 1967. The grout was injected through a grout system installed previous to concrete placement as shown on Drawing No. 622-D-446. A total of 3,153 sacks of 1:1 water-cement ratio by volume grout was injected into the grout systems of the penstock liners.

Draft Tube Tunnel Backfill

Grout was placed to complete the concrete placement of the draft tube tunnels in June 1967. Pipes for the grout and vent holes were placed at high points in the excavated tunnel arch and extended through the form prior to the placement of concrete. After the tunnel lining had been placed the pipes were checked with air and those found tight were drilled into rock with a jackhammer. Grout consisting of a 1:1 water-cement ratio was pumped into the grout pipes beginning at the powerplant end of the tunnels. A total of 2,785 sacks of cement grout was placed into 340 lineal feet of tunnel for an average take of 8.19 sacks of cement per lineal foot of tunnel. No leaks from the construction joints occurred as these contain Type "F" waterstop; however, some negligible leaks did occur from the rock inside the powerplant chamber and from the rock above the draft tube gate structure.

Exploratory Tunnel Backfill

Grout was placed to complete the concrete backfill of exploratory tunnels excavated on the canyon walls. This grout was placed through a grout system installed as shown on Drawing No. 622-D-894. A total of 322 sacks of 1:1 water-cement ratio by volume was injected into the three tunnels for an average take of 2.30 sacks per lineal foot of tunnel.

Foundation Drainage

Foundation drainage for Morrow Point Dam was provided by diamond drilling 3-inch-diameter NX holes into the foundation rock downstream from the grout cut-off curtains. Drilling was initiated in September 1967 and continued until March 1968. Drawing Nos. 622-D-1056, -1057, and -1494 illustrate the general layout of the drain pattern. This pattern was explicitly followed with the exception of additional up holes in the El. 6785 foundation on the left abutment. These additional holes were provided to drain the area grouted by the fan pattern A-holes in the El. 6965 foundation tunnel. Drawing No. 622-427-1899 shows the depths of all holes drilled in the dam foundation gallery and tunnels, which consisted of 23,961 lineal feet of rock and concrete.

In addition to the foundation drainage holes from the dam and foundation tunnels, other holes were drilled in the powerplant drainage tunnel. Drilling was initiated in September 1967 and continued until January 1968. A total of 5,659 lineal feet of hole was drilled in this tunnel as shown on Drawing No. 622-427-1898.

Miscellaneous Drilling and Grouting

In March 1966, the concrete lining of the control cable tunnel was backfill grouted through pipes embedded in the concrete. A total of 296 sacks of 1:1 water-cement ratio by volume grout was placed in approximately 95 lineal feet of tunnel for an average take of 3.12 sacks per lineal foot of tunnel.

In June 1966 the buttress downstream of the right keyway was backfill grouted with 1:1 grout. A total of 83 sacks was injected through pipes embedded in the concrete.

Other backfill grouting accomplished was: access tunnel, inside portal arch, 3 sacks of cement grout; access tunnel, outside portal, 37 sacks cement grout; ventilation tunnel, inside portal, 4 sacks of cement grout, and 3.5-foot by 3.5-foot river outlet conduit, 2 sacks of cement grout.

Numerous gravel or french drains placed in the foundation rock in the dam, stilling basin and draft tube tunnels were grouted and these drains accepted 646 sacks of cement grout.

Continental Drilling Company, subcontractor, also performed other drilling including the following:

Drilling 10-inch-diameter concrete core specimens -	238 feet
Drilling NX core in rock and concrete -	404 feet

Diversion Tunnel

Backfill grouting and pressure grouting of the foundation rock at the diversion tunnel plug section was performed in April and May 1964. A total of 101 sacks of cement grout was required for backfill grouting the 40 foot section in the tunnel plug area.

The four rings of four holes each, 30 feet deep, took 3.5 sacks of 5:1 water-cement ratio by volume grout in 480 lineal feet of rock and concrete for an average take of 0.008 sacks per lineal foot of hole. Maximum pumping pressure for these holes was 100 psi and results are shown on Drawing No. 622-427-1515.

The contractor also performed some pressure grouting immediately downstream from the bulkhead gate seat, in order to consolidate the rock near the bulkhead gate area. Pipes at 10 foot centers were set prior to placing the lining with four holes on each ring. These pipes were used for a combination backfill and low pressure grouting operation. Twenty holes were drilled and grouted in this area which accepted 474 sacks in 600 lineal foot of hole for an average take of 0.79 sack per lineal foot of hole. For results see Drawing No. 622-427-1516.

Backfill and contraction joint grouting of the tunnel plug was performed in March 1968. A total of 64 sacks of cement grout was injected into the system with a holding pressure of 50 psi at completion. Backfill grouting to complete concrete placement of the 18-inch-diameter bypass pipe was also performed in March 1968. A total of 36 sacks of cement grout was injected into the grout system with a holding pressure of 90 psi.

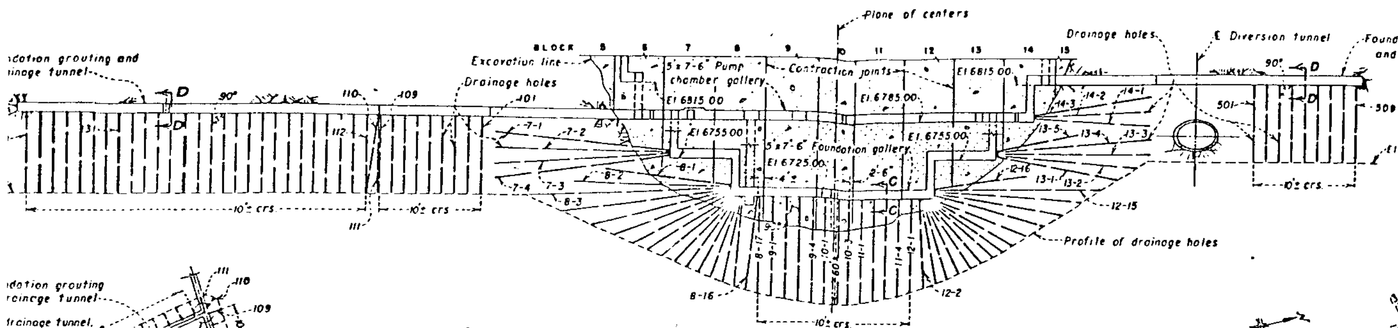
Contraction Joint Grouting

Grouting

Contraction joint grouting of Morrow Point Dam was performed intermittently between November 1966 and May 1968.

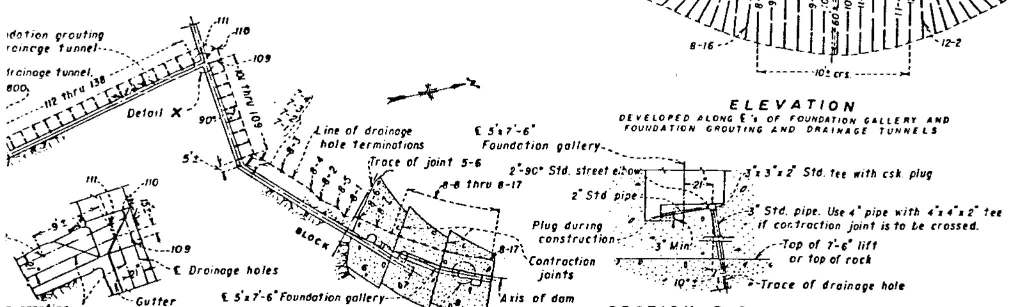
Continental Drilling Company, subcontractor for all drilling and grouting operations at Morrow Point Dam, performed the contraction joint grouting with a crew of six to eight men.

The contraction joints in Morrow Point Dam consist of transverse joints which are separated by metal seals into two areas. A small area, 4-feet 6-inches wide, which is located near the upstream face shall hereafter be designated as a "TT" and the large area of the contraction joint will be designated as a "T". The piping for the contraction joints was installed as shown on Drawing Nos. 622-D-439, -1124, and -1125. Sumps in Blocks 8 and



ELEVATION

DEVELOPED ALONG ℄'s OF FOUNDATION GALLERY AND FOUNDATION GROUTING AND DRAINAGE TUNNELS

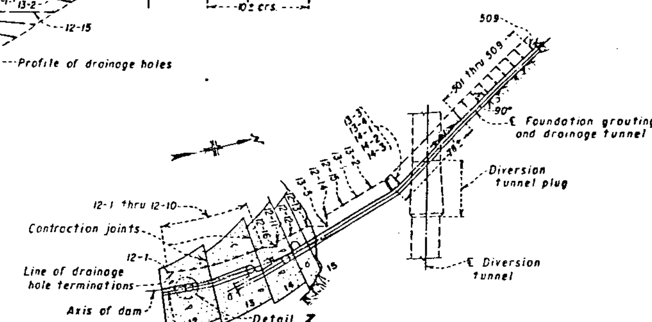


DETAIL X

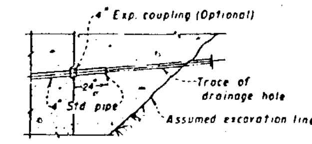
PLAN - LEFT ABUTMENT

SECTION C-C

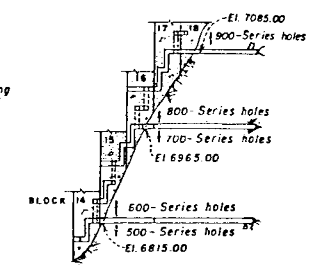
TYPICAL



PLAN - RIGHT ABUTMENT

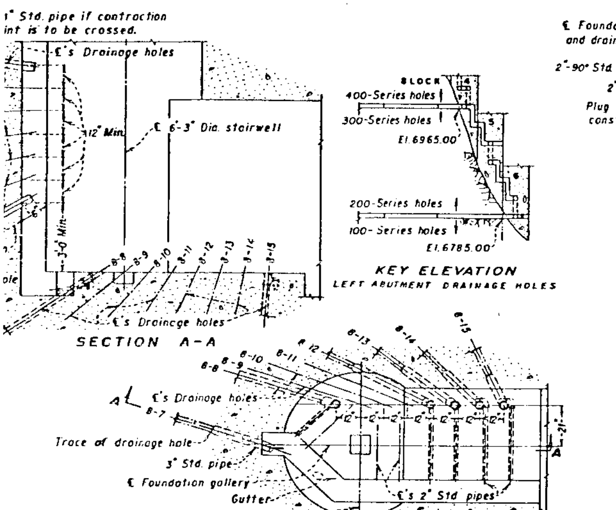


TYPICAL CONTRACTION JOINT CROSSING



KEY ELEVATION

RIGHT ABUTMENT DRAINAGE HOLES



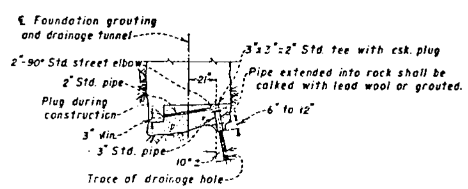
SECTION A-A

KEY ELEVATION

LEFT ABUTMENT DRAINAGE HOLES

DETAIL Y

STAIRWELL DETAILS TYPICAL



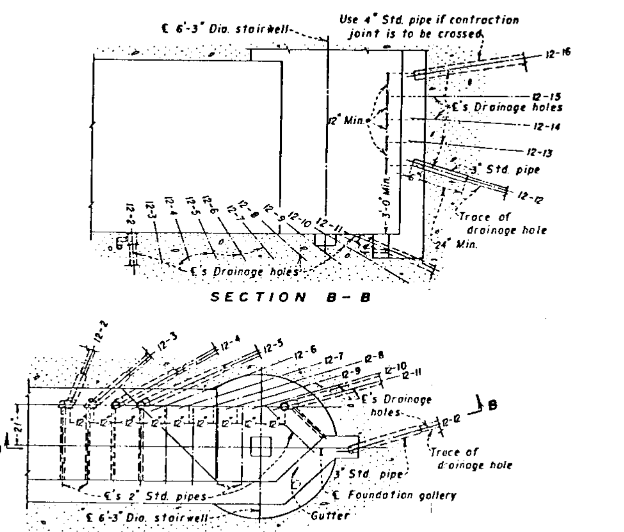
SECTION D-D

TYPICAL

DRAIN. HOLE	SLOPE DEG	BEARING DEG.	APPROX. LGTH-FT.	DRAIN. HOLE	SLOPE DEG	BEARING DEG.	APPROX. LGTH-FT.
110	-80	N 46 W.	61	12-2	-79	N 68 W.	73
111	-80	S 84 W.	61	12-3	-75	N. 40 W.	71
7-1	+6	S. 44 W.	139	12-4	-69	N. 28 W.	70
7-2	+1	S. 45 W.	138	12-5	-63	N. 23 W.	68
7-3	-4	S. 46 W.	138	12-6	-56	N. 19 W.	69
7-4	-8	S. 47 W.	139	12-7	-48	N. 18 W.	72
8-1	+8	S. 40 W.	102	12-8	-41	N. 16 W.	72
8-2	+2	S. 42 W.	123	12-9	-35	N. 15 W.	75
8-3	-3	S. 43 W.	160	12-10	-30	N. 15 W.	76
8-4	-8	S. 43 W.	134	12-11	-22	N. 14 W.	82
8-5	-14	S. 42 W.	113	12-12	-16	N. 16 W.	92
8-6	-21	S. 42 W.	97	12-13	-10	N. 16 W.	101
8-7	-29	S. 43 W.	84	12-14	-3	N. 16 W.	117
8-8	-34	S. 42 W.	78	12-15	+1	N. 17 W.	132
8-9	-40	S. 43 W.	75	12-16	+8	N. 15 W.	73
8-10	-49	S. 45 W.	71	13-1	-10	N. 23 W.	98
8-11	-55	S. 47 W.	69	13-2	-5	N. 23 W.	110
8-12	-63	S. 51 W.	65	13-3	0	N. 21 W.	122
8-13	-70	S. 59 W.	69	13-4	+6	N. 20 W.	123
8-14	-75	S. 70 W.	70	13-5	+13	N. 18 W.	66
8-15	-79	N 69 W.	73	14-1	-2	N. 24 W.	95
8-16	-79	S 86 W.	77	14-2	+4	N. 23 W.	94
				14-3	+10	N. 22 W.	95

ORIENTATION OF HOLES

HOLES NOT TABULATED SHALL BE AS SHOWN ON DRAWING



SECTION B-B

DETAIL Z

STAIRWELL DETAILS TYPICAL

4-5-68 ADDED POWER PLANT DRAINAGE TUNNEL

NOTES

Diameter of drainage holes shall be approximately 3".

Where necessary, shift drainage holes to clear surfaces of shafts or openings by 15".

Unless otherwise directed, drainage holes shall not be drilled until all adjacent grout holes within a minimum distance of 250' have been drilled and grouted.

For details of foundation grouting and drainage tunnels, see Dwg. 622-D-779.

All dimensions measured on ℄'s of gallery or tunnels, unless otherwise specified.

Depth, spacing, and orientation of drainage holes shall be as shown unless otherwise directed by the contracting officer.

For sheets 2 of 3 and 3 of 3, see Dwgs. 622-D-1057 and 622-D-1494.

1-19-66	ADDED 132 THRU 138 DRAINAGE HOLES.
6-25-65	REVISED TO CONFORM WITH ACTUAL EXCAVATION, REVISED DRAIN HOLE 8-1 AND 900-SERIES HOLES RIGHT ABUTMENT KEY ELEVATION, AND ADDED NOTE.

THIS DRAWING SUPERSEDES DWG CEE D-436 IN PART

ALWAYS THINK SAFETY

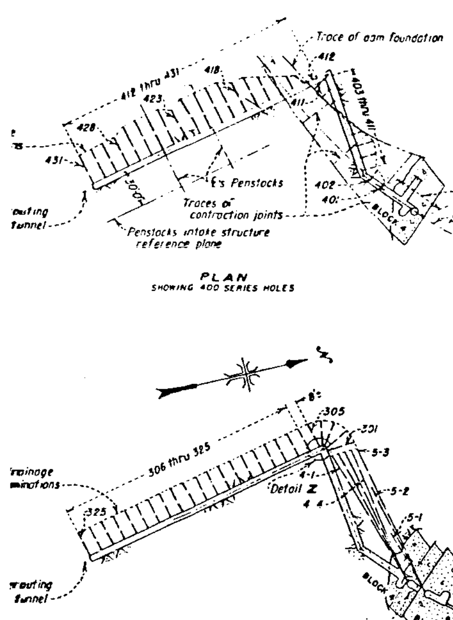
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER STORAGE PROJECT
GUNNISON DIVISION-CURECANTI UNIT-COLORADO

MORROW POINT DAM

FOUNDATION DRAINAGE

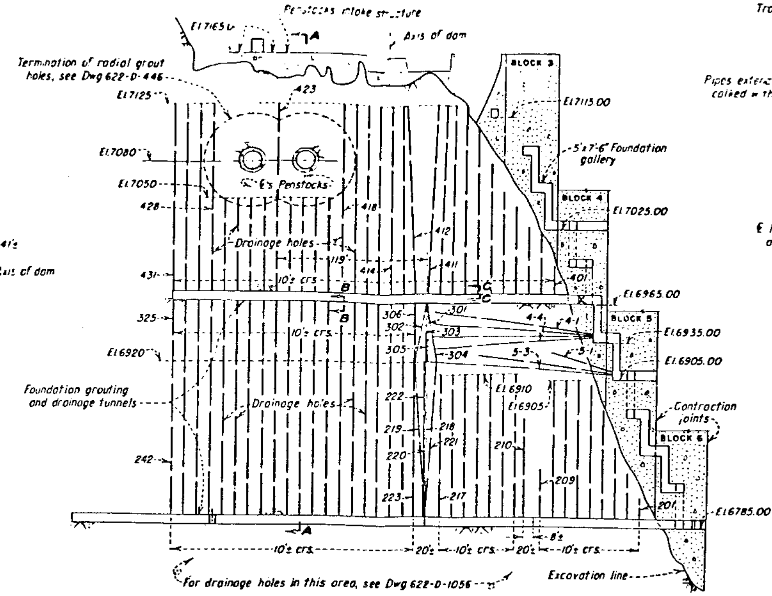
DRAWN W.E.T. SUBMITTED Charles L. Townsend
TRACED C.W.B. RECOMMENDED May Ind
CHECKED [illegible] APPROVED R. J. Larson CHIEF, DAMS BRANCH

DENVER, COLORADO, FEB. 8, 1965 SHEET 1 OF 3 | 622-D-1056

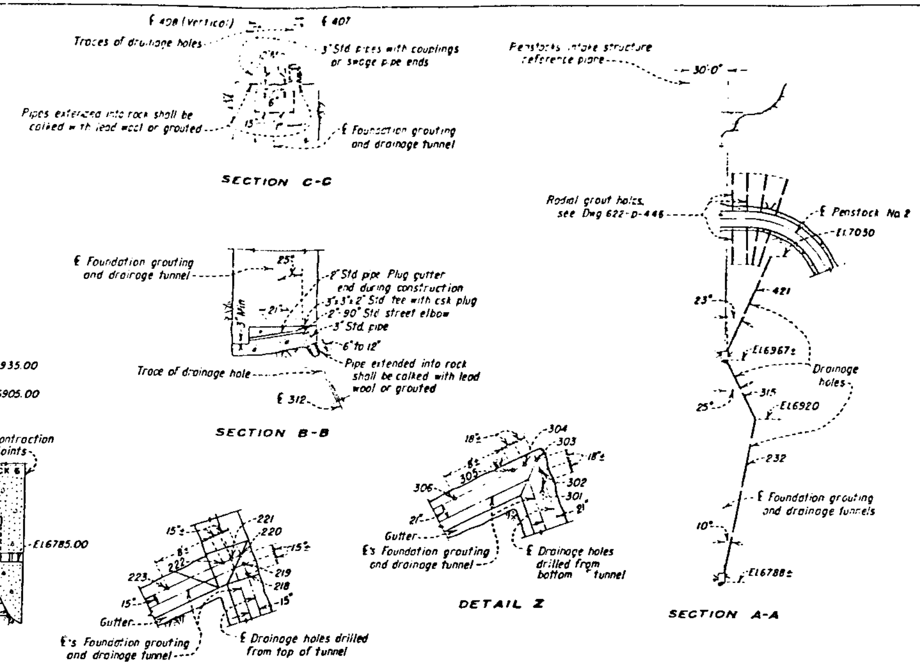


PLAN
SHOWING 400 SERIES HOLES

PLAN
SHOWING 4, 5, AND 300 SERIES HOLES



ELEVATION - LEFT ABUTMENT
DEVELOPED ALONG ℄'S OF FOUNDATION GROUTING AND DRAINAGE TUNNELS



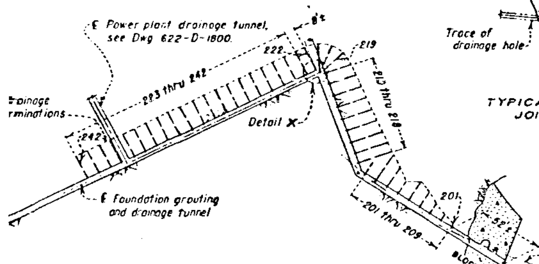
SECTION C-C

SECTION B-B

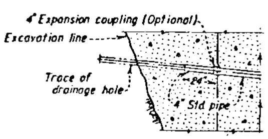
DETAIL X

DETAIL Z

SECTION A-A



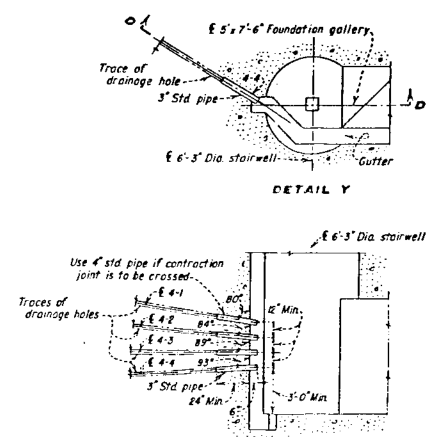
PLAN
SHOWING 200 SERIES HOLES



TYPICAL CONTRACTION JOINT CROSSING

DRAINAGE HOLE	DEG. FROM VERTICAL	BEARING DEG.	APPROX. LGTH-FT.	DRAINAGE HOLE	DEG. FROM VERTICAL	BEARING DEG.	APPROX. LGTH-FT.
401	10	N.41W.	23	4-3	89	S.79W.	115
402	10	N.41W.	50	4-4	93	S.81W.	116
403	10	N.6W.	55	301	25	N.6W.	51
404	10	N.6W.	71	302	25	N.30W.	51
405	10	N.6W.	83	303	25	N.54W.	51
406	5	N.6W.	104	304	25	N.78W.	51
407	1	N.6W.	131	305-325	25	S.77W.	52
408	0	-	145	201	10	N.44W.	18
409	2	S.36E.	152	202	10	N.44W.	38
410	4	S.36E.	152	203	10	N.44W.	58
411	6	S.36E.	152	204	10	N.44W.	88
412	4	S.8E.	152	205	10	N.44W.	109
413	4	S.61W.	152	206	7	N.44W.	113
414	5	S.77W.	152	207	10	N.44W.	114
415	6	S.77W.	152	208	13	N.44W.	115
416	8	S.77W.	153	209	17	N.44W.	43
417-418	10	S.77W.	153	210	15	N.6W.	83
419-422	23	S.77W.	82	211-212	14	N.6W.	119
423	10	S.77W.	153	213-214	13	N.6W.	119
424-427	23	S.77W.	82	215-216	12	N.6W.	118
428-431	10	S.77W.	152	217	11	N.6W.	118
5-1	73	S.74W.	57	218	10	N.6W.	128
5-2	81	S.77W.	95	219	10	N.30W.	128
5-3	85	S.79W.	129	220	10	N.54W.	128
4-1	80	S.74W.	119	221	10	N.78W.	127
4-2	84	S.76W.	117	222 thru 242	10	S.77W.	127

ORIENTATION OF HOLES



DETAIL Y

SECTION D-D
5 SERIES HOLES SIMILAR

NOTES

Diameter of drainage holes shall be approximately 3".
Unless otherwise directed, drainage holes shall not be drilled until all adjacent grout holes within a minimum distance of 250' have been drilled and grouted.
For details of foundation grouting and drainage tunnels, see Dwg. 622-D-779.
All dimensions measured on ℄'s of gallery or tunnels, unless otherwise specified.
Depth, spacing, and orientation of drainage holes shall be as shown unless otherwise directed by the contracting officer.
For sheets 1 of 3 and 3 of 3, see Dwgs. 622-D-1056 and 622-D-1494.

THIS DRAWING SUPERSEDES DWG. 622-D-436 IN PART

ALWAYS THINK SAFETY

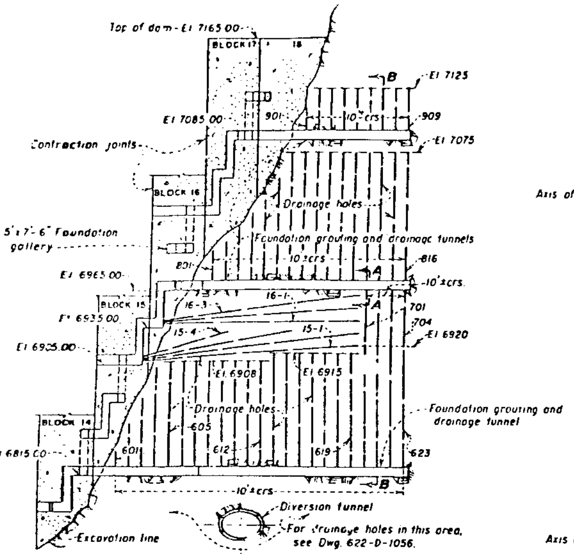
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER STORAGE PROJECT
GUNNISON DIVISION - CURECANTI UNIT - COLORADO

MORROW POINT DAM
FOUNDATION DRAINAGE

DRAWN R.A.T. SUBMITTED
TRACED R.A.P. RECOMMENDED
CHECKED APPROVED

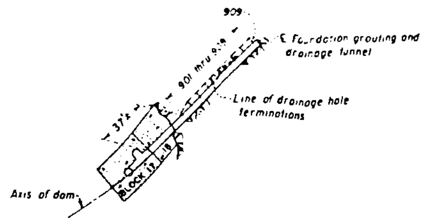
DENVER, COLORADO APRIL 5, 1965
SHEET 2 OF 3

622-D-1057



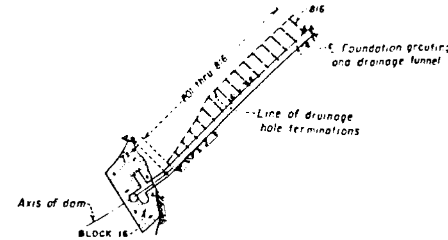
ELEVATION-RIGHT ABUTMENT

DEVELOPED ALONG ℄s OF FOUNDATION GROUTING AND DRAINAGE TUNNELS



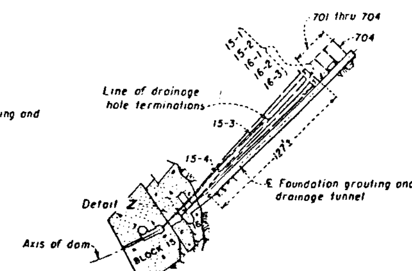
PLAN

SHOWING 900 SERIES HOLES



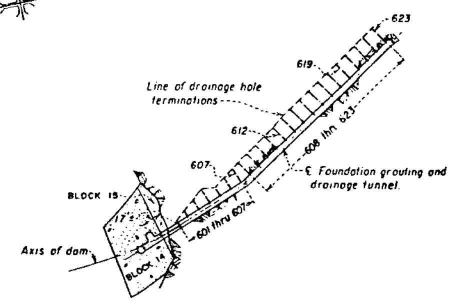
PLAN

SHOWING 800 SERIES HOLES



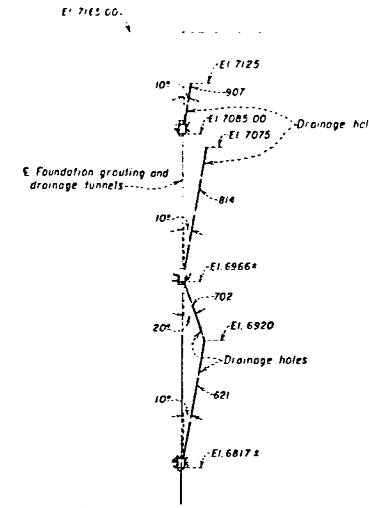
PLAN

SHOWING 15,16 AND 700 SERIES HOLES

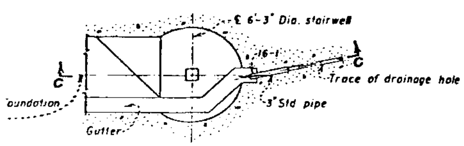


PLAN

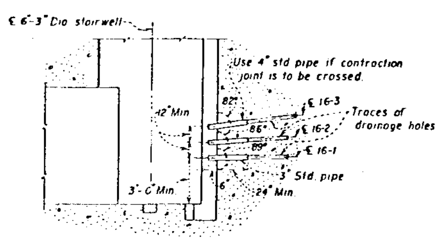
SHOWING 600 SERIES HOLES



SECTION B-B

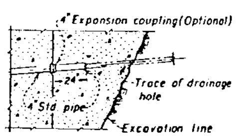


DETAIL Z

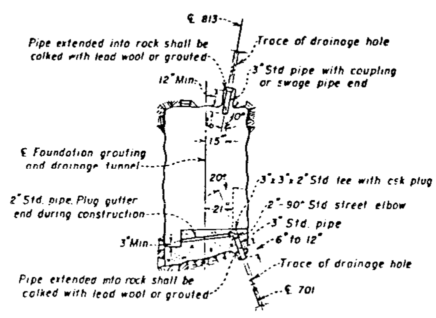


SECTION C-C

15 SERIES HOLES SIMILAR



TYPICAL CONTRACTION JOINT CROSSING



SECTION A-A

DRAINAGE HOLE	DEG FROM VERTICAL	BEARING DEG.	APPROX. LGTH.-FT.
901	10	S.58 W.	17
902-909	10	S.58 W.	33
801	10	S.58 W.	23
802	10	S.58 W.	32
803	10	S.58 W.	43
804	10	S.58 W.	53
805	10	S.58 W.	65
806	10	S.58 W.	84
807-815	10	S.58 W.	103
16-1	89	N.34 W.	150
16-2	86	N.33 W.	150
16-3	82	N.32 W.	151
15-1	66	N.36 W.	166
15-2	83	N.34 W.	167
15-3	79	N.33 W.	117
15-4	72	N.32 W.	68
701-704	20	S.58 W.	49
601	10	S.70 W.	13
602	10	S.70 W.	35
603	10	S.70 W.	56
604	10	S.70 W.	91
605	6	S.70 W.	86
606	8	S.70 W.	86
607	9	S.70 W.	86
608-612	10	S.58 W.	86
613-619	10	S.58 W.	93
620-623	10	S.58 W.	97

ORIENTATION OF HOLES

NOTES

Diameter of drainage holes shall be approximately 3".
Unless otherwise directed, drainage holes shall not be drilled until all adjacent grout holes within a minimum distance of 250' have been drilled and grouted.
For details of foundation grouting and drainage tunnels, see Dwg. 622-D-779.
All dimensions measured on ℄'s of gallery or tunnels, unless otherwise specified.
Depth, spacing, and orientation of drainage holes shall be as shown unless otherwise directed by the contracting officer.
For sheets 1 of 3 and 2 of 3, see Dwgs. 622-D-1056 and 622-D-1057.

THIS DRAWING SUPERSEDES DWG 622-D-436 IN PART

ALWAYS THINK SAFETY

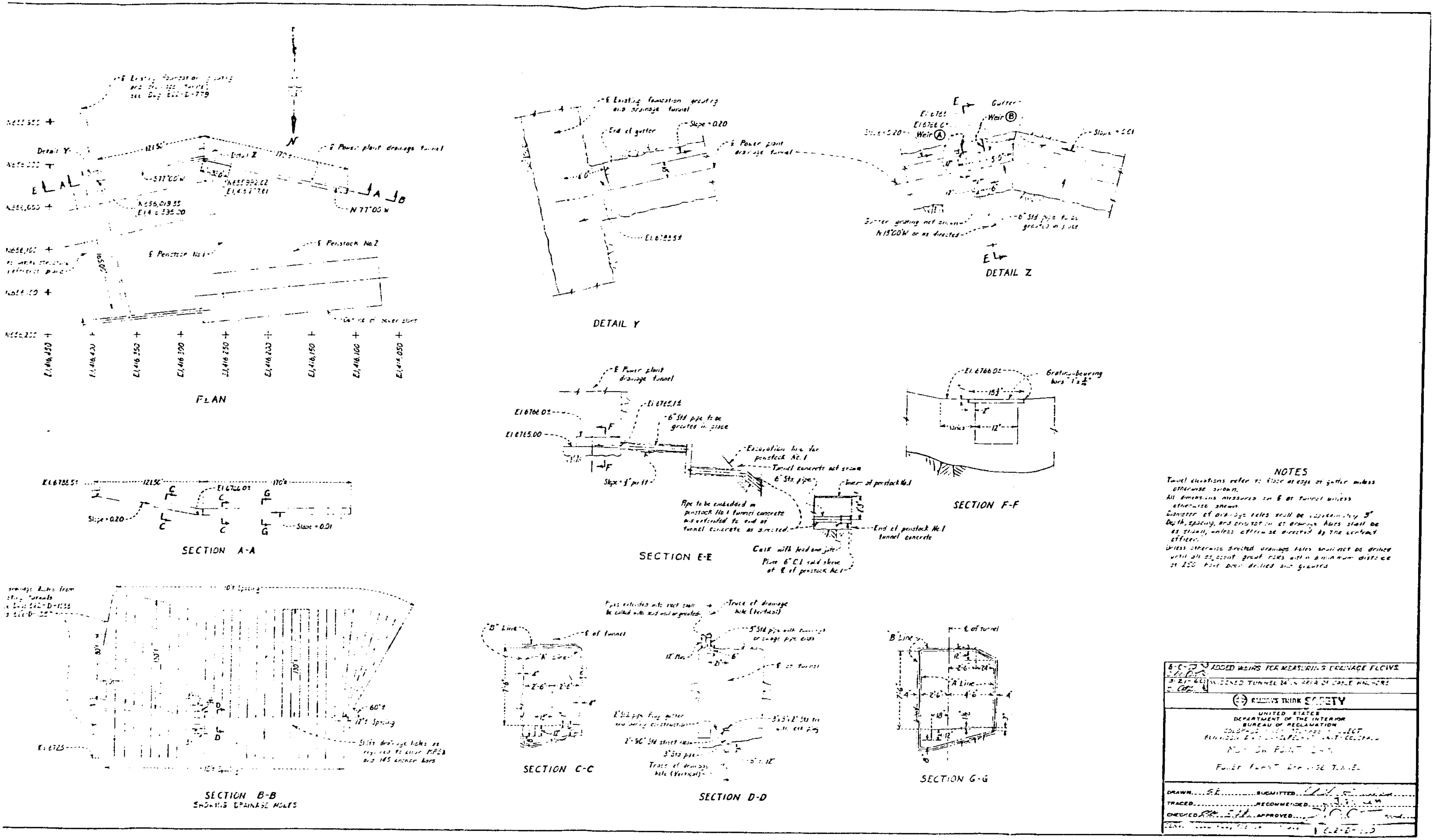
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER STORAGE PROJECT
GUNNISON DIVISION-CURECANTI UNIT-COLORADO

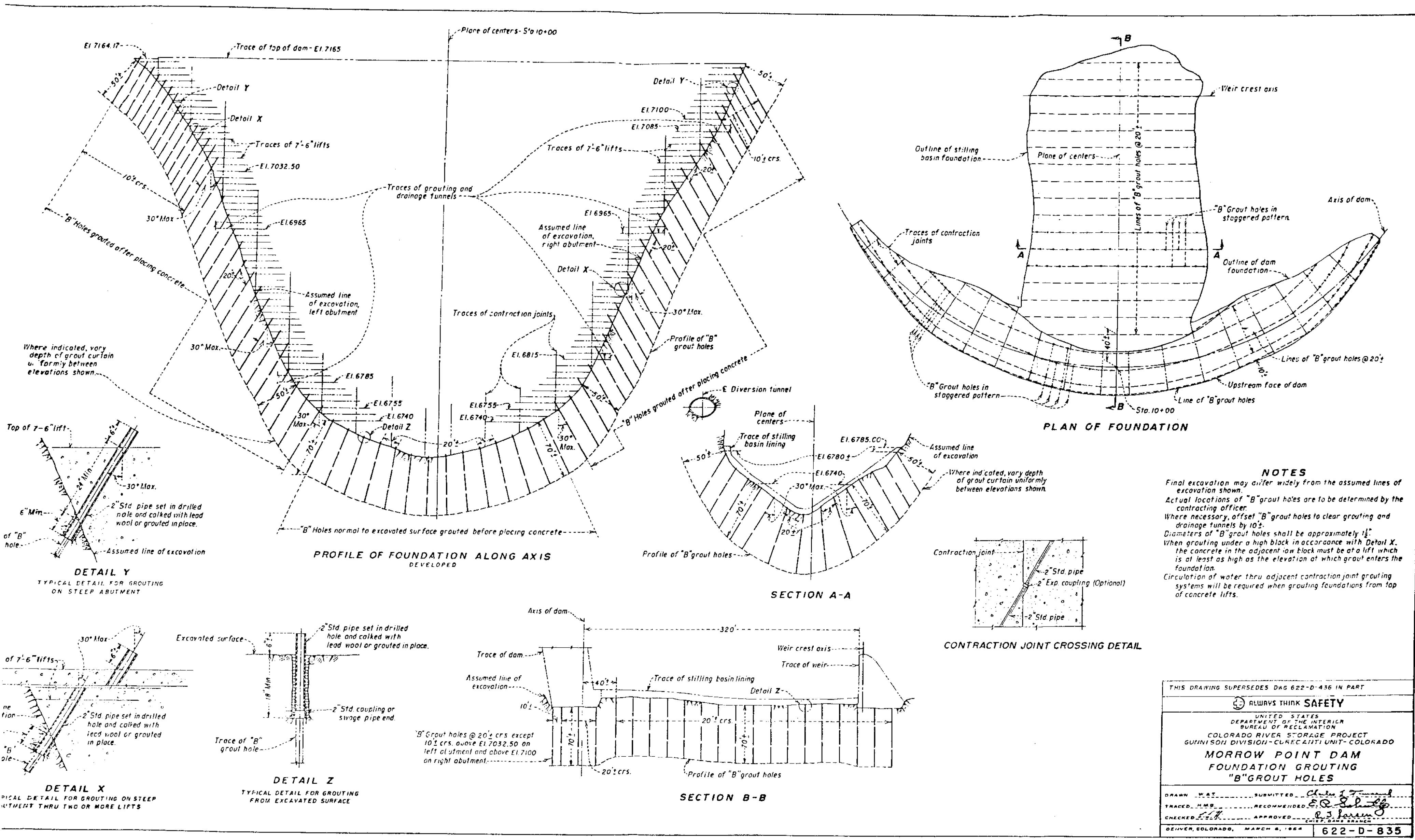
MORROW POINT DAM
FOUNDATION DRAINAGE

DRAWN W.A.T. SUBMITTED
TRACED R.E.H. RECOMMENDED
CHECKED JR. APPROVED

DENVER, COLORADO, APRIL 8, 1966
SHEET 3 OF 3

622-D-1494


PLAN
DETAIL Y
DETAIL Z
SECTION A-A
SECTION B-B
SHOWING DRAINAGE HOLES
SECTION C-C
SECTION D-D
SECTION E-E
SECTION F-F
SECTION G-G
℄ Power plant drainage tunnel
℄ Penstock No.1
℄ Penstock No.2
N 77°00' W
Slope = 0.20
Slope = 0.01
End of gutter
Weir Ⓐ
Weir Ⓑ
Gutter
El. 6766.0±
El. 6765.00
6" Std pipe to be grouted in place
Excavation line for penstock No.1
Tunnel concrete not shown
Pipe to be embedded in penstock No.1 tunnel concrete and extended to end of tunnel concrete as directed.
End of penstock No.1 tunnel concrete
Calk with lead and jute
Grating-bearing bars
"B" Line
"A" Line
℄ of tunnel
60°±
12'± Spacing
10'± Spacing
NOTES
Tunnel elevations refer to floor at edge of gutter unless otherwise shown.
All dimensions measured on ℄ of tunnel unless otherwise shown.
Diameter of drainage holes shall be approximately 3"
Depth, spacing, and orientation of drainage holes shall be as shown, unless otherwise directed by the contracting officer.
Unless otherwise directed drainage holes shall not be drilled until all adjacent grout holes with a minimum distance of 200 have been drilled and grouted
ADDED WEIRS FOR MEASURING DRAINAGE FLOWS
WIDENED TUNNEL 24" IN AREA OF CABLE ANCHORS
THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
POWER PLANT DRAINAGE TUNNEL
DRAWN
SUBMITTED
TRACED
RECOMMENDED
CHECKED
APPROVED



NOTES

Final excavation may differ widely from the assumed lines of excavation shown.

Actual locations of "B" grout holes are to be determined by the contracting officer.

Where necessary, offset "B" grout holes to clear grouting and drainage tunnels by 10'±.

Diameters of "B" grout holes shall be approximately 1½".

When grouting under a high block in accordance with Detail X, the concrete in the adjacent low block must be at a lift which is at least as high as the elevation at which grout enters the foundation.

Circulation of water thru adjacent contraction joint grouting systems will be required when grouting foundations from top of concrete lifts.

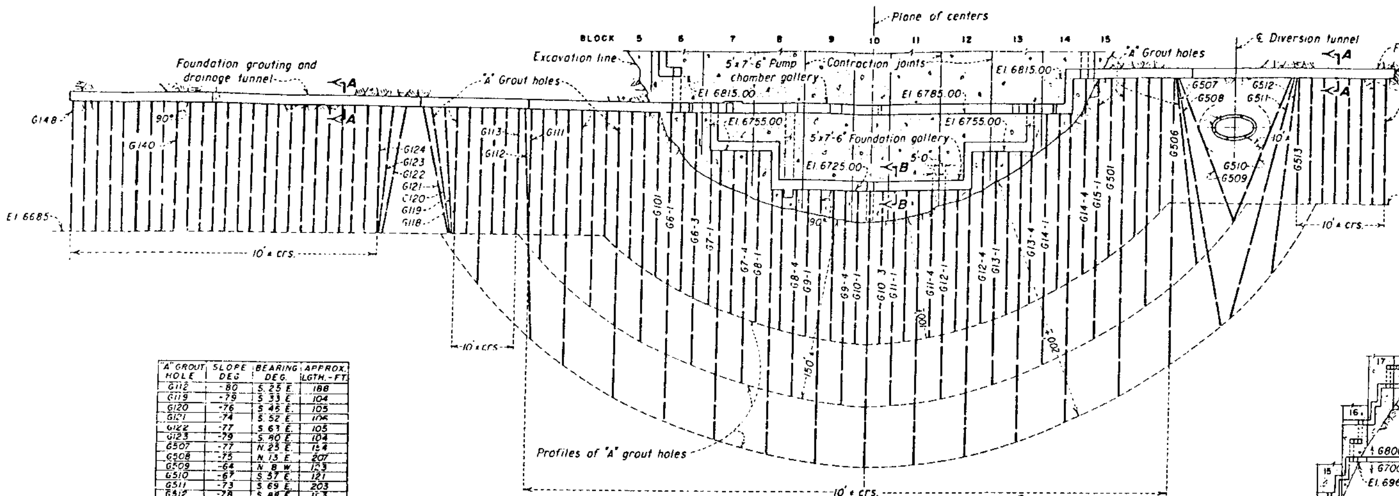
THIS DRAWING SUPERSEDES DWG 622-D-436 IN PART

ALWAYS THINK SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER STORAGE PROJECT
GUNNISON DIVISION - CURECANTI UNIT - COLORADO

MORROW POINT DAM
FOUNDATION GROUTING
"B" GROUT HOLES

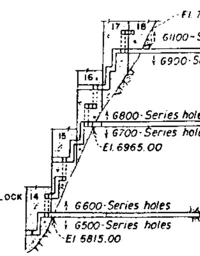
DRAWN W.A.T. SUBMITTED
TRACED H.M.B. RECOMMENDED
CHECKED APPROVED CHIEF, DAMS BRANCH
DENVER, COLORADO, MARCH 6, 1964 622-D-835



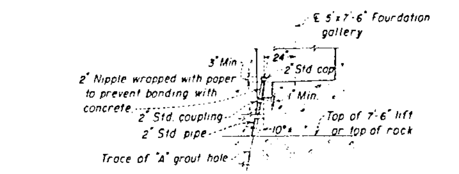
"A" GROUT HOLE	SLOPE DEG	BEARING DEG.	APPROX. LGTH.-FT.
G112	-80	S. 25 E.	188
G119	-79	S 33 E	104
G120	-76	S 45 E.	105
G121	-74	S. 52 E.	106
G122	-77	S. 63 E.	105
G123	-79	S. 80 E.	104
G507	-77	N. 25 E.	154
G508	-75	N. 13 E.	207
G509	-64	N 8 W.	123
G510	-67	S. 57 E.	121
G511	-73	S. 69 E.	203
G512	-78	S 88 E.	113

ORIENTATION OF HOLES
HOLES NOT TABULATED SHALL BE AS SHOWN ON DRAWING

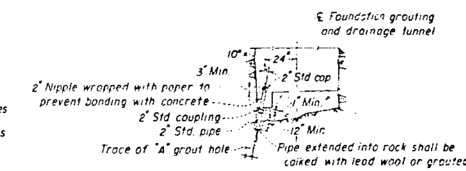
ELEVATION
DEVELOPED ALONG ℄'s OF FOUNDATION GALLERY AND FOUNDATION GROUTING AND DRAINAGE TUNNELS



KEY ELEVATION
RIGHT ABUTMENT "A" GROUT HOLES



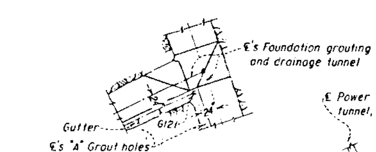
SECTION B-B
TYPICAL



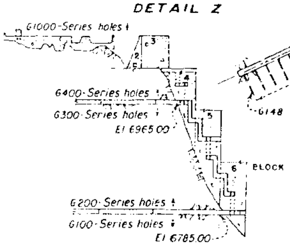
SECTION A-A
TYPICAL

NOTES

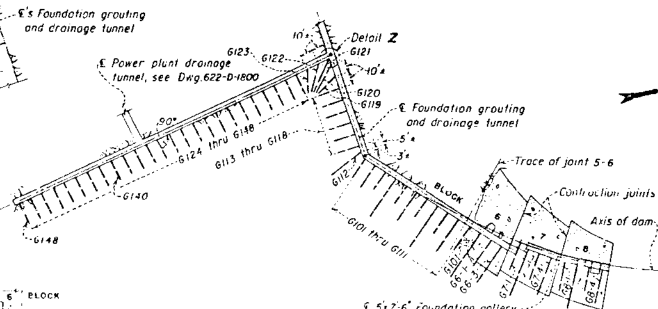
Diameter of grout holes shall be approximately $1\frac{1}{2}$".
Where necessary, shift grout holes longitudinally or along gutter to clear surfaces of stairwells or shafts by 15".
For details of foundation grouting and drainage tunnels, see Dwg. 622-D-779.
All dimensions measured on ℄'s of gallery or tunnels, unless otherwise specified.
Depth, spacing and orientation of grout holes shall be as shown unless otherwise directed by the contracting officer.
For sheets 2 of 3 and 3 of 3, see Dwgs. 622-D-1055 and 622-D-1493.



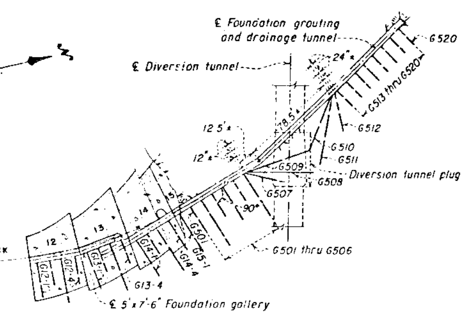
DETAIL Z



KEY ELEVATION
LEFT ABUTMENT GROUT HOLES



PLAN - LEFT ABUTMENT



PLAN - RIGHT ABUTMENT

4-5-66		ADDED POWER PLANT DRAINAGE TUNNEL
1-19-66		ADDED 141 THRU 148 "A" GROUT HOLES
8-25-65		REVISED TO CONFORM WITH ACTUAL EXCAVATION ADDED G1000 AND G1100 SERIES HOLES TO ABUTMENT KEY ELEVATIONS AND ADDED NOTE

THIS DRAWING SUPERSEDES DWG. 622-D-436 IN PART

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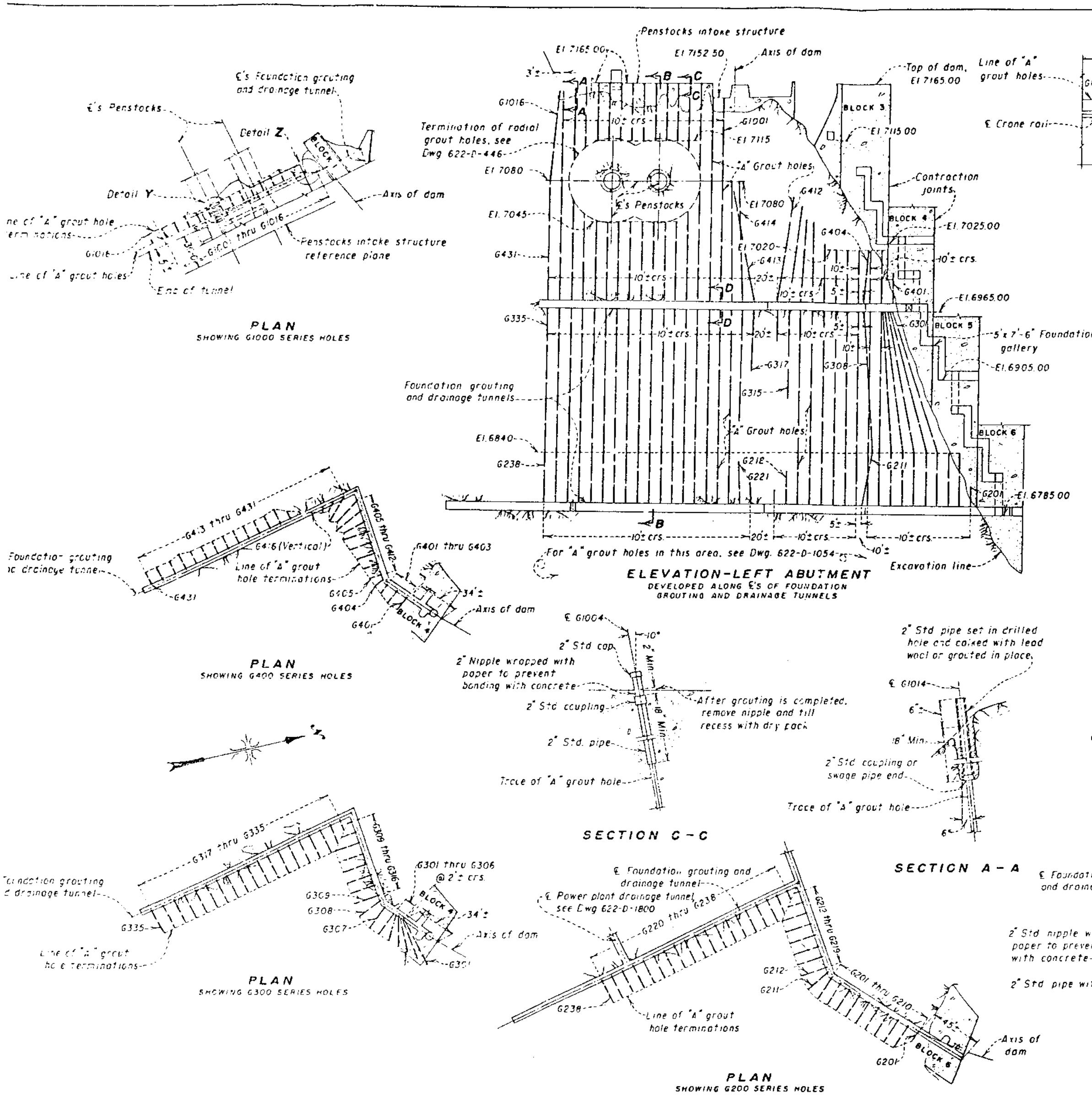
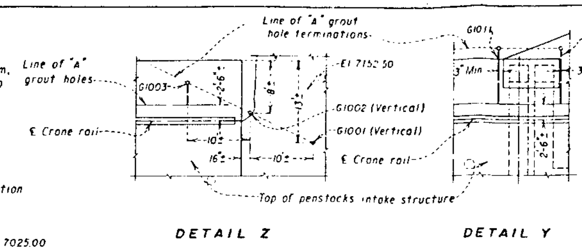
BUREAU OF RECLAMATION
COLORADO RIVER STORAGE PROJECT
GUNNISON DIVISION - CURECANTI UNIT - COLORADO

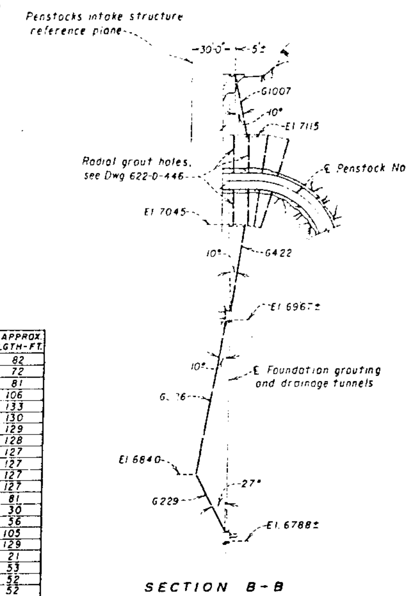
MORROW POINT DAM
FOUNDATION GROUTING
"A" GROUT HOLES

DRAWN W.A.T. SUBMITTED [signature]
TRACED [illegible] RECOMMENDED [signature]
CHECKED [illegible] APPROVED R. J. Larsen CHIEF, DAMS BRANCH

DENVER, COLORADO, FEBRUARY [illegible] SHEET 1 OF 3 | 622-D-1054

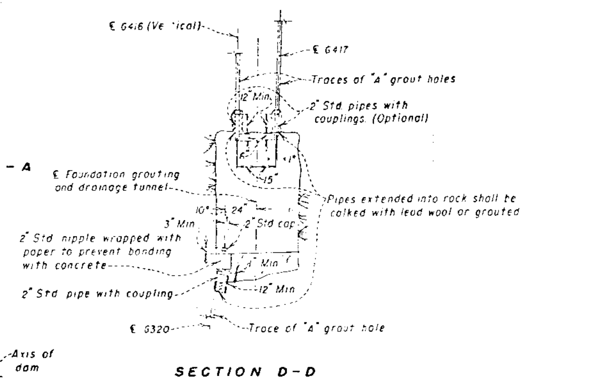






"A" GROUT HOLE	DEG. FROM VERTICAL	BEARING DEG.	APPROX. LGTH-FT.	"A" GROUT HOLE	DEG. FROM VERTICAL	BEARING DEG.	APPROX. LGTH-FT.
G1001-G1002	0	–	73	G419	10	S77W	82
G1003	2	S77W	85	G420-G427	10	S77W	72
G1004	10	S77W	61	G428	10	S77W	81
G1005-G1012	10	S77W	51	G429-G431	7	S77W	106
G1013	10	S77W	57	G301	20	N75E	133
G1014	6	S77W	82	G302	17	N81E	130
G1015	6	S77W	80	G303	15	N89E	129
G1016	8	S38W	80	G304	13	S79E	128
G401	26	S41E	31	G305	11	S61E	127
G402	16	S41E	49	G306-G307	10	S41E	127
G403	13	S41E	49	G308	10	S25E	127
G404	12	S24E	49	G309-G314	10	S6E	127
G405	14	S6E	49	G315	10	S6E	81
G406	18	S6E	49	G316	10	S6E	30
G407	21	S6E	50	G317	10	N86E	56
G408	21	S6E	56	G318	10	N81E	105
G409	18	S6E	74	G319-G335	10	N77E	129
G410	16	S18E	74	G201	27	S44E	21
G411	19	S28E	89	G202-G210	27	S44E	53
G412	16	S35E	97	G211	27	S28E	52
G413	14	S47E	100	G212-G217	27	S6E	52
G414	4	S51E	107	G218	27	S6E	32
G415	2	S74E	106	G219	27	S6E	13
G416	0	–	106	G220	29	N87E	23
G417	1	S77W	106	G221	28	N83E	42
G418	4	S77W	106	G222-G238	27	N77E	51

ORIENTATION OF HOLES



NOTES

Diameter of grout holes shall be approximately $1\frac{1}{2}$"
For details of foundation grouting and drainage tunnels, see Dwg. 622-D-779.
All dimensions measured on ℄'s of galleries or tunnels unless otherwise specified
Depth, spacing and orientation of grout holes shall be as shown unless otherwise directed by the contracting officer
For sheets 1 of 3 and 3 of 3, see Dwgs 622-D-1054 and 622-D-1493.

THIS DRAWING SUPERSEDES DWG 622-D-436 IN PART

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UNITED STATES
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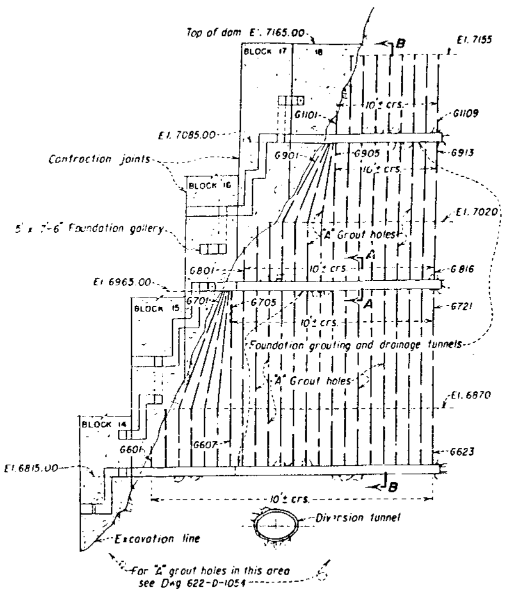
COLORADO RIVER STORAGE PROJECT
GUNNISON DIVISION-CURECANTI UNIT-COLORADO

MORROW POINT DAM

FOUNDATION GROUTING "A" GROUT HOLES

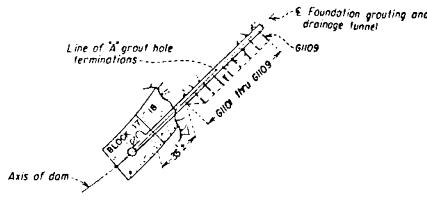
DRAWN W.A.T. SUBMITTED E. L. [illegible]
TRACED C.W.B. RECOMMENDED [illegible]
CHECKED [illegible] APPROVED [illegible]

DENVER, COLORADO, APRIL 3, 1964 SHEET 2 OF 3 | 622-D-1055



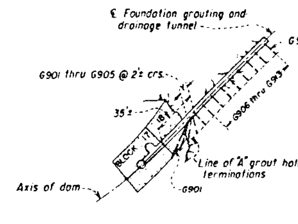
ELEVATION - RIGHT ABUTMENT

DEVELOPED ALONG ℄'s OF FOUNDATION GROUTING AND DRAINAGE TUNNELS



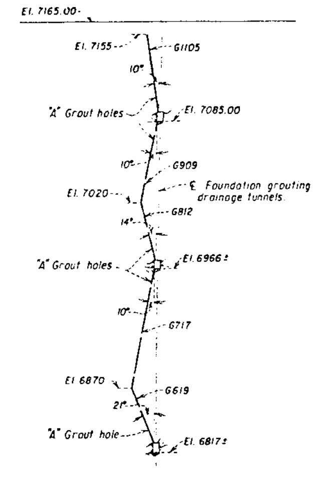
PLAN

SHOWING G1100 SERIES HOLES

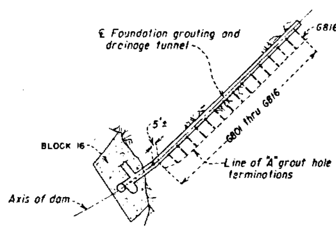


PLAN

SHOWING G900 SERIES HOLES

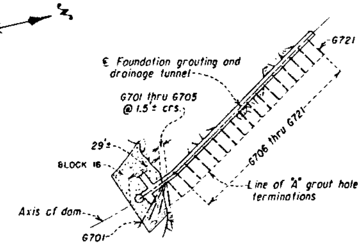


SECTION B-B



PLAN

SHOWING G800 SERIES HOLES



PLAN

SHOWING G700 SERIES HOLES

NOTES

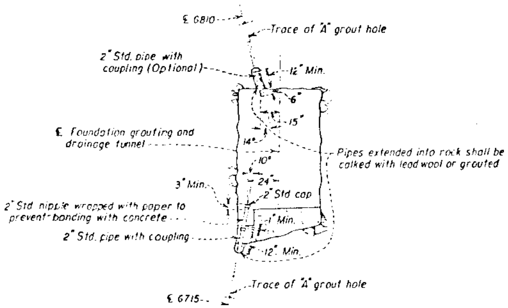
Diameter of grout holes shall be approximately $1\frac{1}{2}$".

For details of foundation grouting and drainage tunnels, see Dwg 622-D-779.

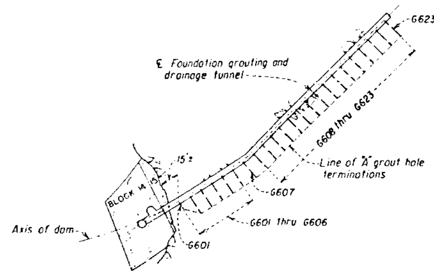
All dimensions measured on ℄'s of galleries or tunnels unless otherwise specified.

Depth, spacing and orientation of grout holes shall be as shown unless otherwise directed by the contracting officer.

For sheets 1 of 3 and 2 of 3, see Dwgs. 622-D-1054 and 622-D-1055.



SECTION A-A



PLAN

SHOWING G600 SERIES HOLES

"A" GROUT HOLE	DEG. FROM VERTICAL	BEARING DEG.	APPROX. LGTH-FT.
G1101	10	N58E	17
G1102 - G1109	10	N58E	64
G901	28	S52E	73
G902	22	S58E	70
G903	17	S67E	68
G904	12	S86E	67
G905 - G913	10	N58E	66
G801	14	N58E	28
G902	14	N58E	45
G803 - G816	14	N58E	48
G701	22	S45E	102
G702	18	S52E	100
G703	14	S63E	98
G704	11	S81E	97
G705	10	N64E	97
G706 - G721	10	N58E	97
G601	21	N70E	18
G602 - G606	21	N70E	51
G607	21	N63E	51
G608 - G623	21	N58E	51

ORIENTATION OF HOLES

THIS DRAWING SUPERSEDES DWG 622-D-436 IN PART

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UNITED STATES
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COLORADO RIVER STORAGE PROJECT
GUNNISON DIVISION-CURECANTI UNIT-COLORADO

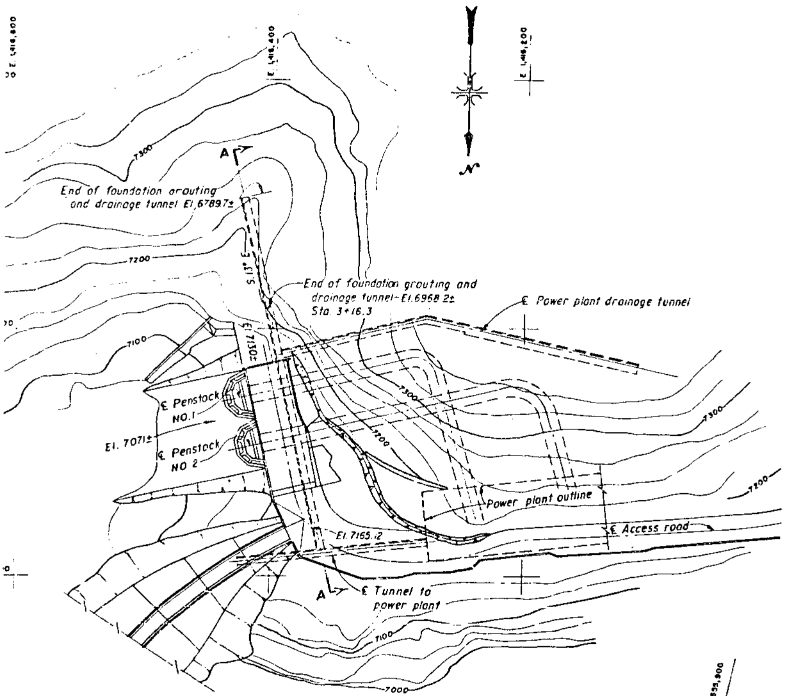
MORROW POINT DAM

FOUNDATION GROUTING "A" GROUT HOLES

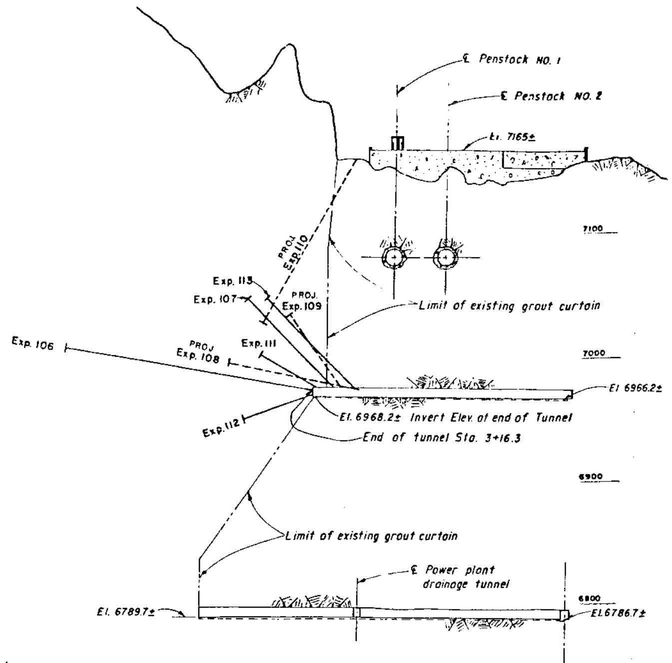
DRAWN W.A.T. SUBMITTED [illegible]
TRACED R.L.M. RECOMMENDED [illegible]
CHECKED [illegible] APPROVED [illegible]
ACT. CHIEF, DAMS BRANCH

DENVER, COLORADO, APRIL 5, 196[illegible]
SHEET 3 OF 3

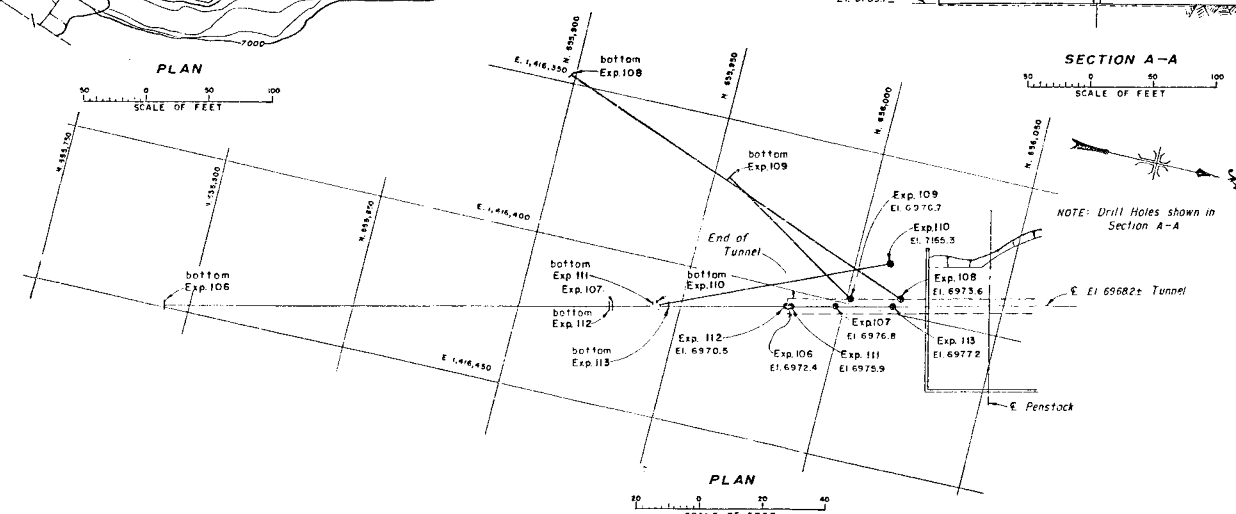
622-D-1493



PLAN



SECTION A—A



PLAN

NOTES

Exploratory Drill Holes No. 106 thru 113 were grouted with cationic asphalt emulsion. Some of these hole are still making small amounts of water. Flows from these holes on 9-17-69 with the reservoir at elevation 7072.40 were as follows:

Exp. 106	— 1.9	gallons per minute
Exp. 107	— 1.3	gallons per minute
Exp. 108	— 1.5	gallons per minute
Exp. 109	—	dry
Exp. 110	—	plugged
Exp. 111	— 2.4	gallons per minute
Exp. 112	— 8.1	gallons per minute
Exp. 113	— 12.3	gallons per minute

Complete geologic logs of these drill holes are included in the specifications and are arranged to follow this drawing.

● Collar of Exploratory Drill Hole

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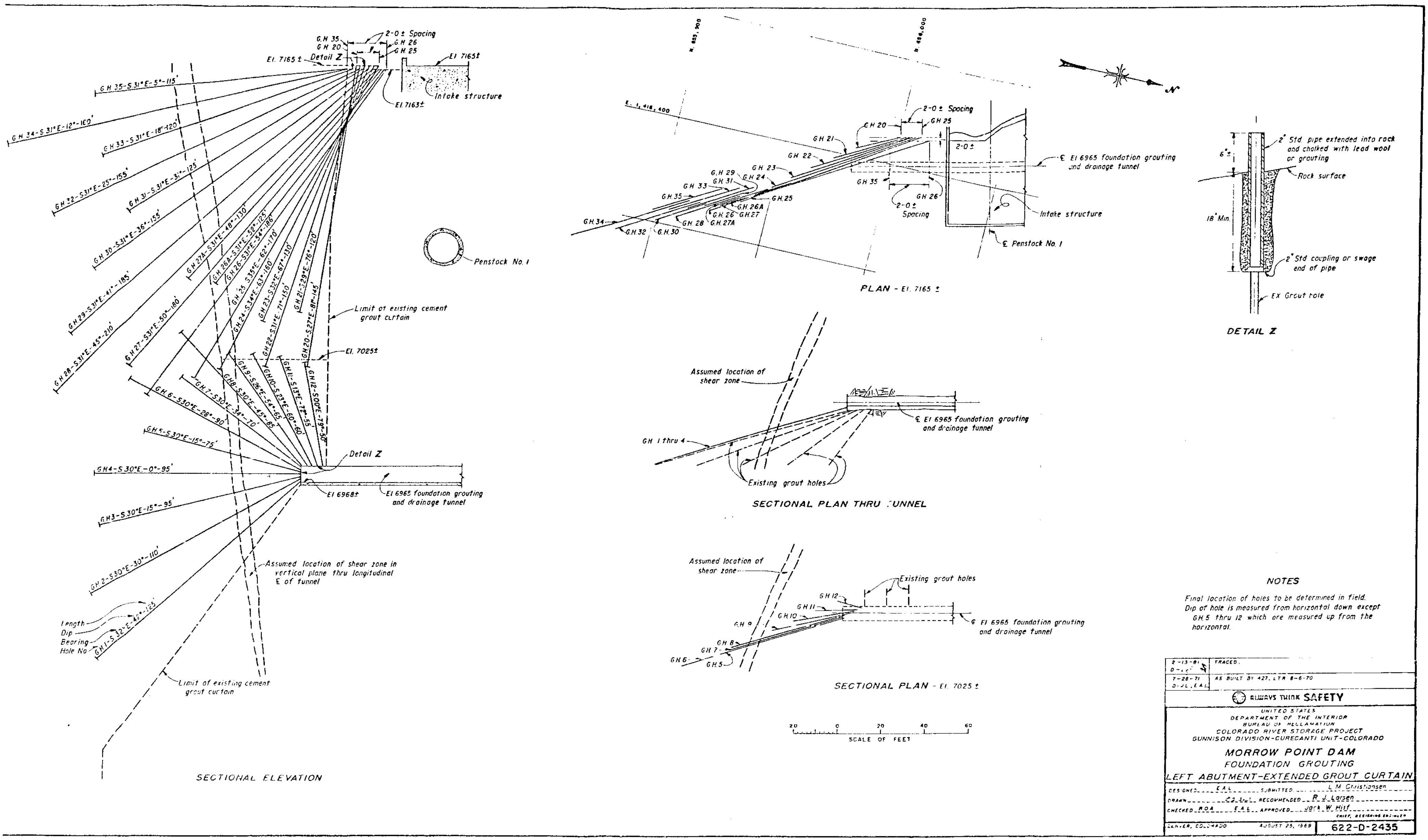
GUNNISON DIVISION—CURECANTI UNIT—COLORADO

MORROW POINT DAM
FOUNDATION GROUTING
GROUTING EXPLORATION

DRAWN D.U.A. SUBMITTED Lewis E. Kline
TRACED J.H.W. RECOMMENDED M. D. Logan
CHECKED L.E.K. APPROVED [signature]

DENVER, COLORADO, SEPTEMBER 26, 1969 | 622-D-2439



SECTIONAL ELEVATION
PLAN - El. 7165 ±
SECTIONAL PLAN THRU TUNNEL
SECTIONAL PLAN - El. 7025 ±
DETAIL Z
2" Std. pipe extended into rock and chalked with lead wool or grouting
Rock surface
18" Min.
2" Std coupling or swage end of pipe
Ex Grout hole
Penstock No. 1
Intake structure
Limit of existing cement grout curtain
Assumed location of shear zone in vertical plane thru longitudinal ℄ of tunnel
Assumed location of shear zone
Existing grout holes
℄ El 6965 foundation grouting and drainage tunnel
Detail Z
El. 7165 ±
El. 7163 ±
El. 7025 ±
El 6968 ±
2-0 ± Spacing
Length
Dip
Bearing
Hole No
GH 1 thru 4
NOTES
Final location of holes to be determined in field.
Dip of hole is measured from horizontal down except GH.5 thru 12 which are measured up from the horizontal.
SCALE OF FEET
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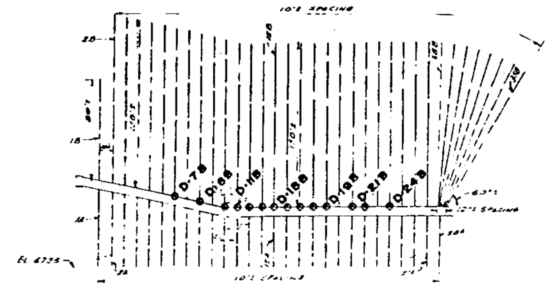
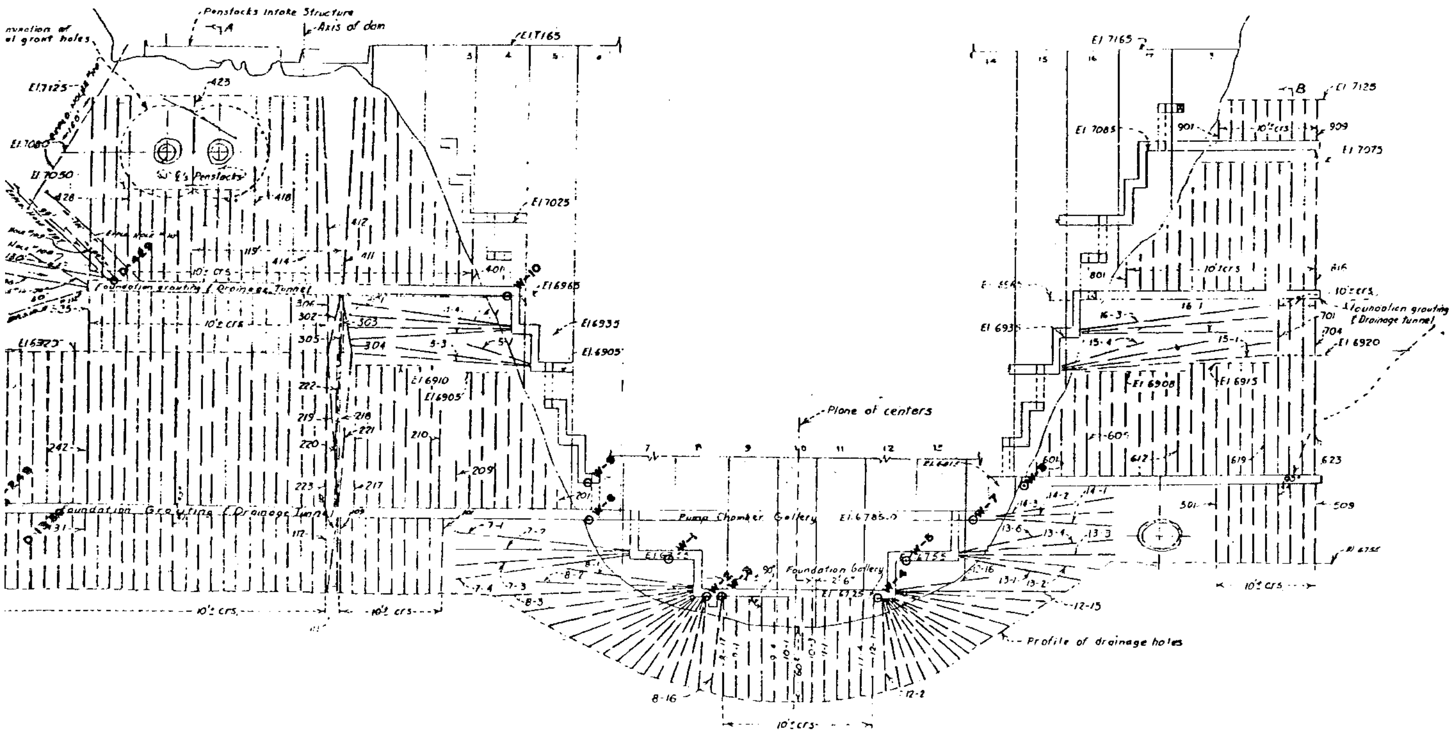
GUNNISON DIVISION-CURECANTI UNIT-COLORADO
MORROW POINT DAM
FOUNDATION GROUTING
LEFT ABUTMENT-EXTENDED GROUT CURTAIN
L. M. Christiansen
R. J. Larsen
Jack W. Hilf
DENVER, COLORADO
AUGUST 25, 1969
622-D-2435



POWER PLANT DRAINAGE TUNNEL



ELEVATION

⊖ D-1 Drainage Measurement Point - Drain Holes

⊖ W-1 " " " - Weirs

10-4-69 427	ADDED HOLES #105 #110 # 111, #115 & #118.
5-8-69 427	REVISED HOLES #106 & #107. ADDED HOLE #109
3-7-65 427	DELETED WEIRS W-4 & W-5 ALSO DRAINS D-217, D704 & D-693 ADDED EXPLO. HOLE #107
3-4-69 427	ADDED WEIRS, DRAIN HOLES AND EXPLORATORY DRILL HOLES.

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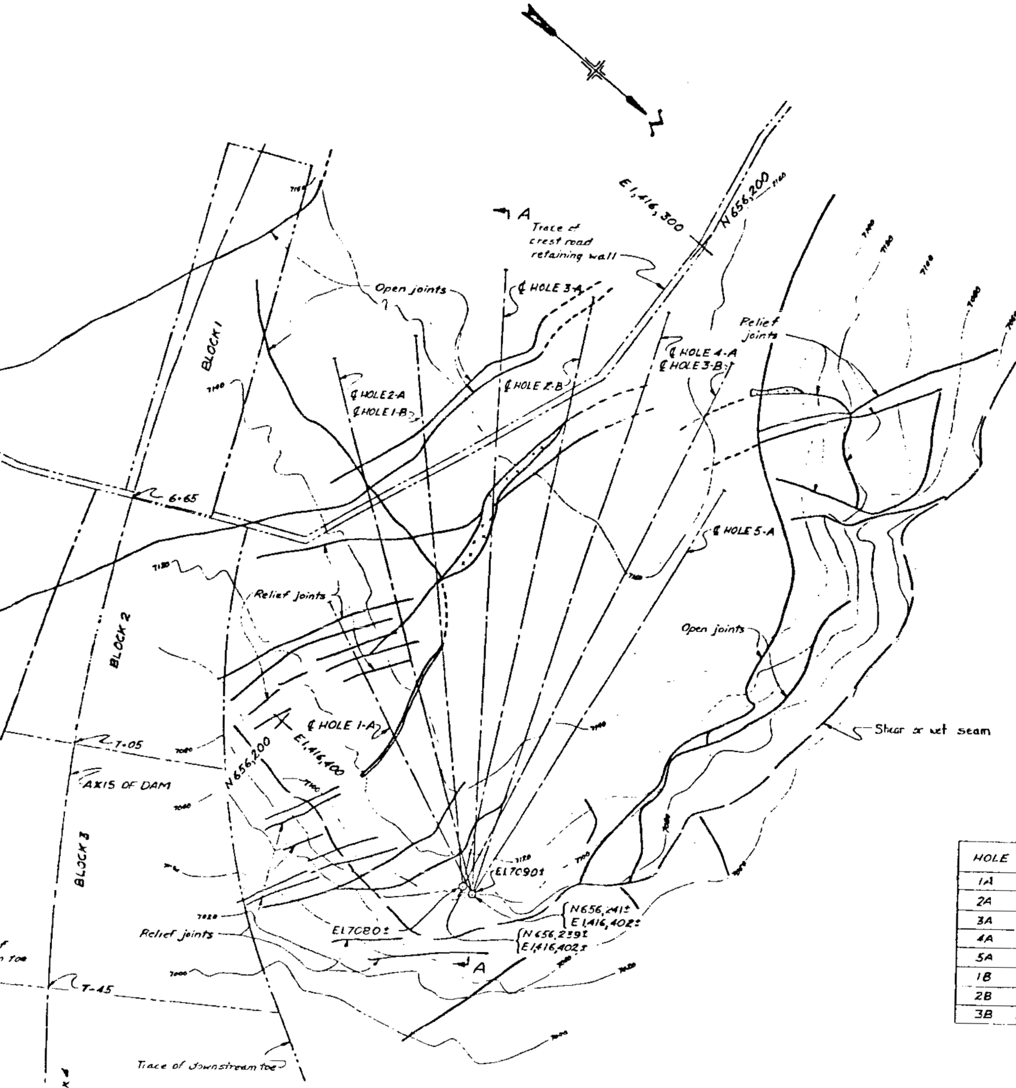
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

CURECANTI UNIT

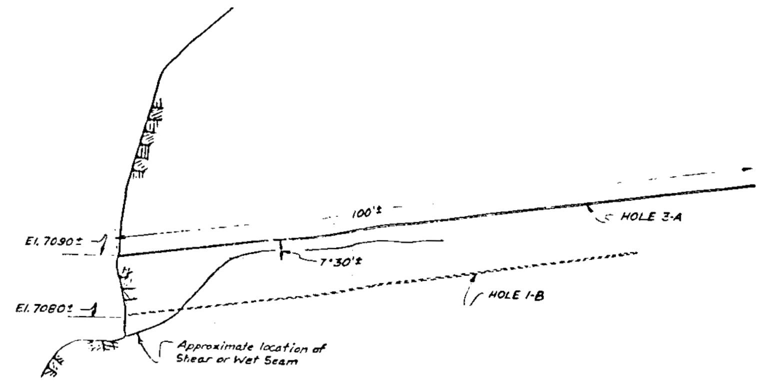
MORROW POINT DAM
FOUNDATION DRAINAGE HOLES

DRAWN C.T. SUBMITTED
TRACED RECOMMENDED
CHECKED APPROVED

MONTROSE, COLO. FEB 19, 1969 622-427-1116



PLAN



SECTION A-A

DRAIN HOLE DATA

HOLE	BEARING	LENGTH	ANGLE FROM HORIZONTAL	COLLAR LOCATION
1A	S24°±W	55'±	8°±	N 656,241± E 1,416,402± El. 7090±
2A	S35°±W	90'±	8°±	
3A	S52°±W	100'±	7°30'±	
4A	S67°±W	100'±	6°±	
5A	S81°±W	75'±	3°±	
1B	S44°±W	90'±	11°±	N 656,239± E 1,416,402± El 7080±
2B	S61°±W	100'±	11°±	
3B	S76°±W	95'±	5°±	

NOTE

Drainholes to be drilled NX size.

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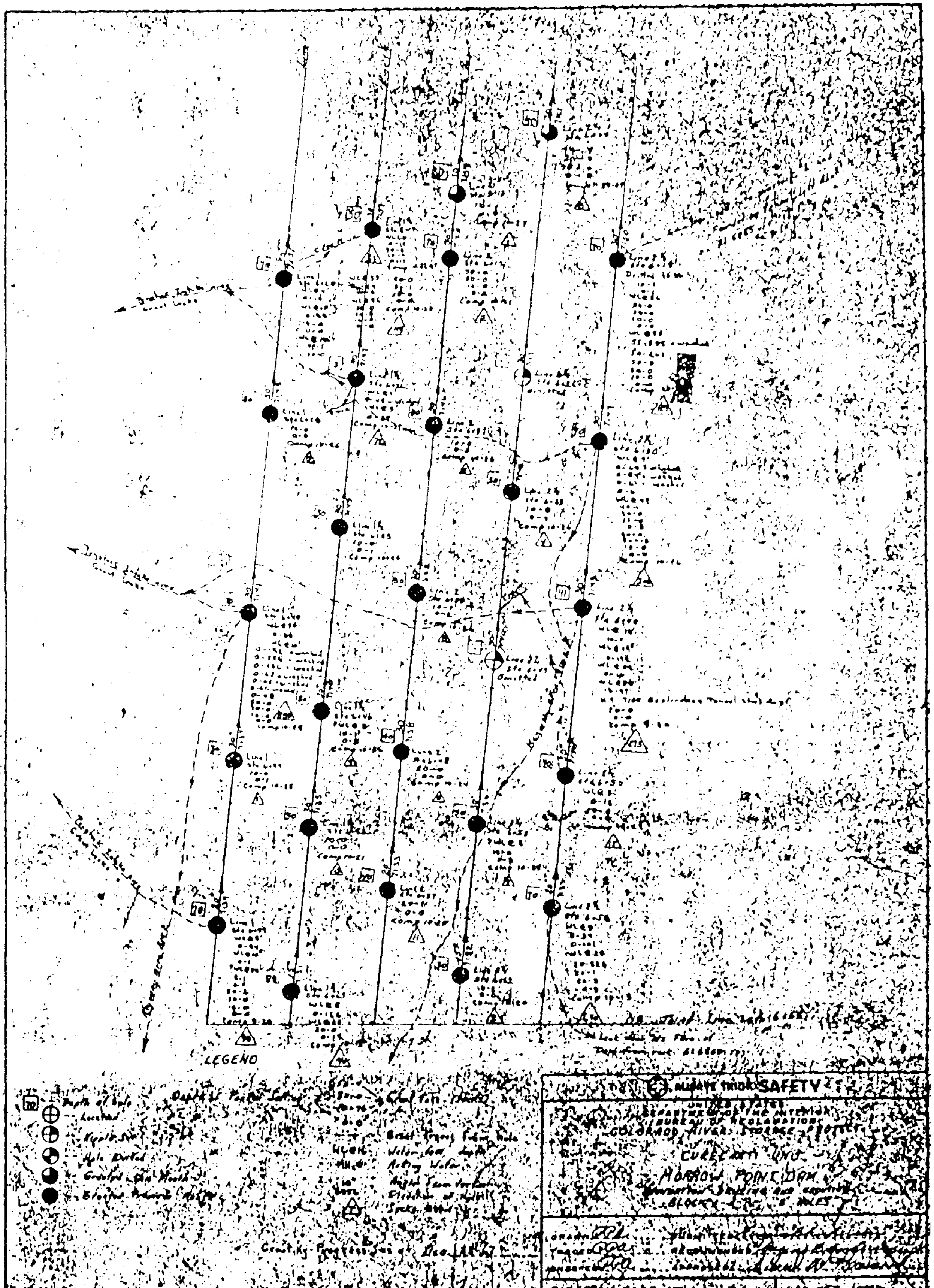
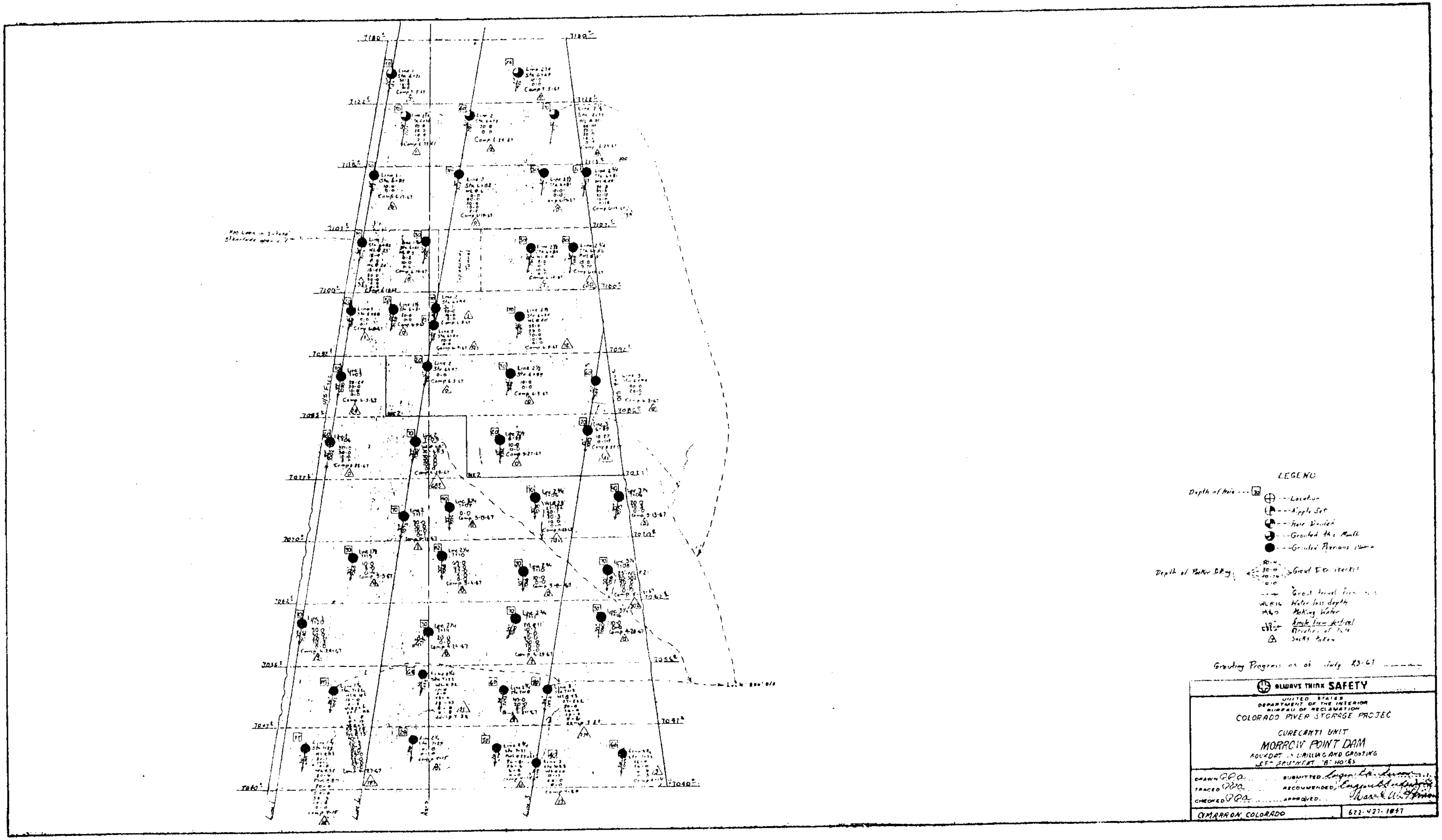
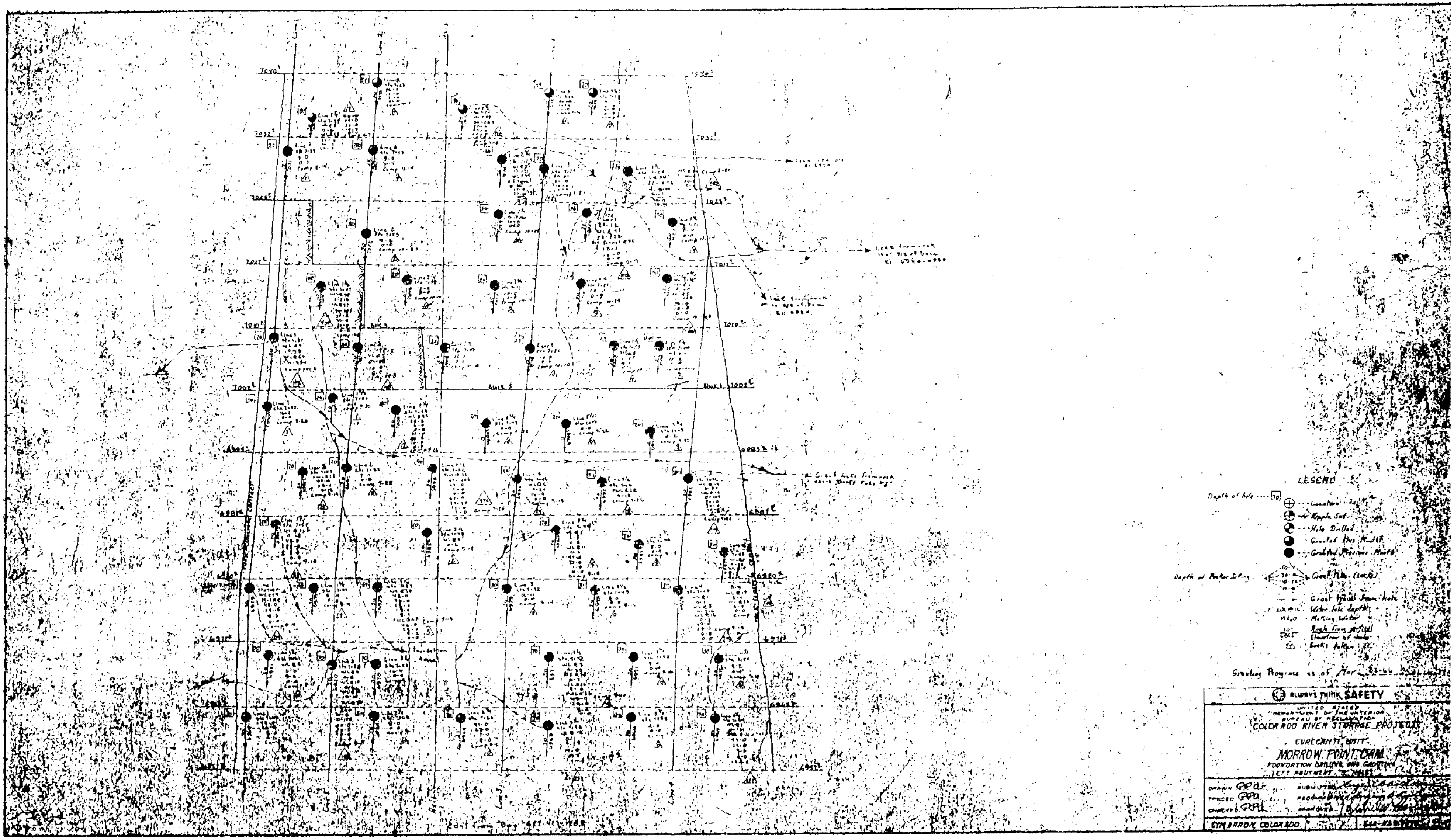
COLORADO RIVER STORAGE PROJECT
GUNNISON DIVISION-CURECANTI UNIT-COLORADO

MORROW POINT DAM
LEFT ABUTMENT
DOWNSTREAM DRAIN HOLES

DRAWN EMS .... SUBMITTED E.A. Lindblom
TRACED .... RECOMMENDED
CHECKED MA .... APPROVED R.J. [illegible]
DENVER, COLORADO. NOV. 5, 1967 | 622-D-2358


LEGEND
SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER STORAGE PROJECT
CURECANTI UNIT
MORROW POINT DAM
CIMARRON, COLO.


LEGEND
Depth of Hole
Location
Nipple Set
Hole Drilled
Water loss depth
Making Water
Sacks taken
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER STORAGE PROJEC
CURECANTI UNIT
MORROW POINT DAM
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
CIMARRON, COLORADO
622-427-1047


LEGEND
Depth of hole
Location
Nipple Set
Hole Drilled
Grouted this Month
Grouted Previous Month
Depth of Packer Setting
Grout Take (sacks)
Grout flowed from hole
Water hole depth
Making Water
Angle from vertical
Elevation of hole
Sacks taken
ALWAYS THINK SAFETY
UNITED STATES
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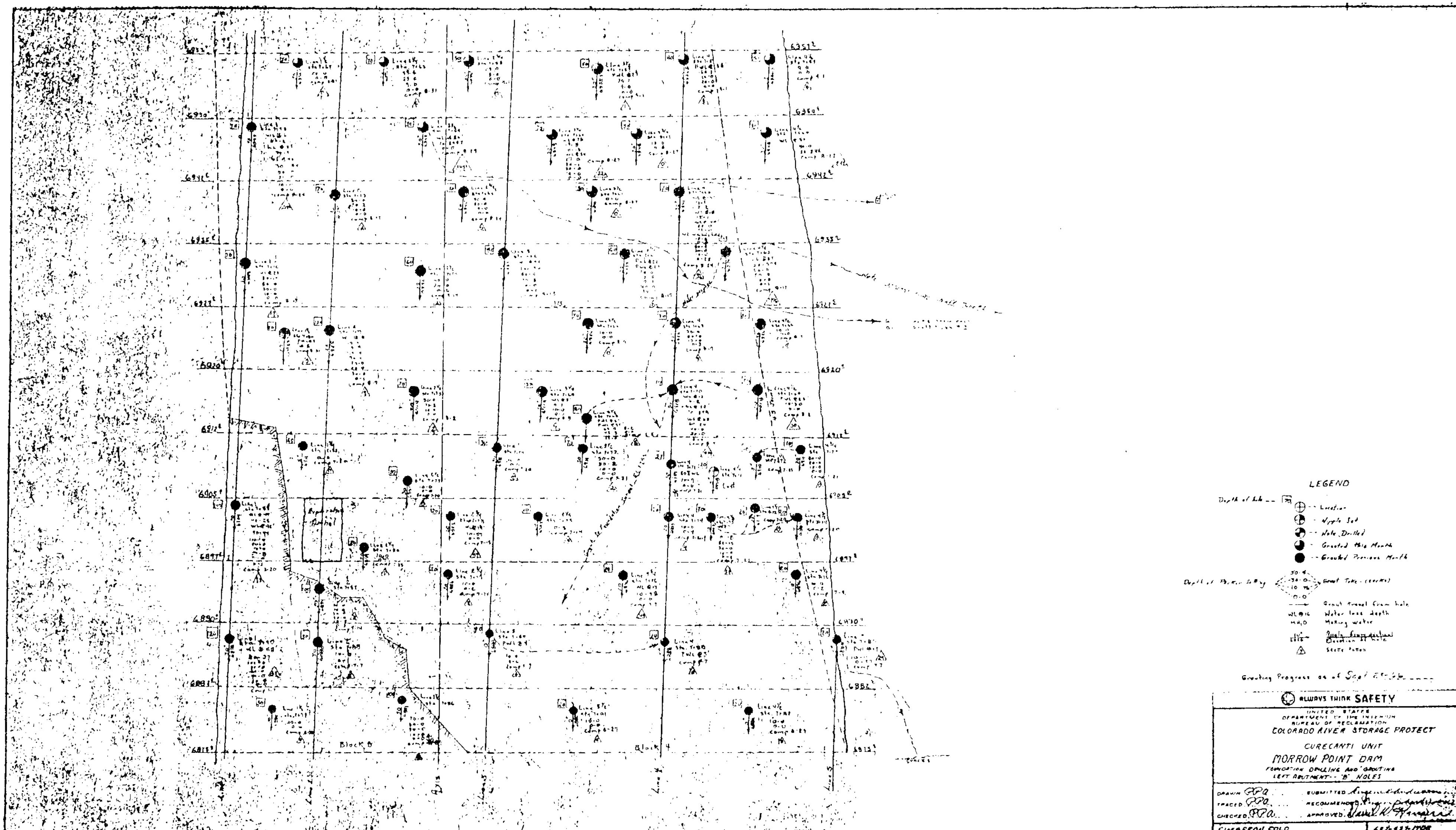
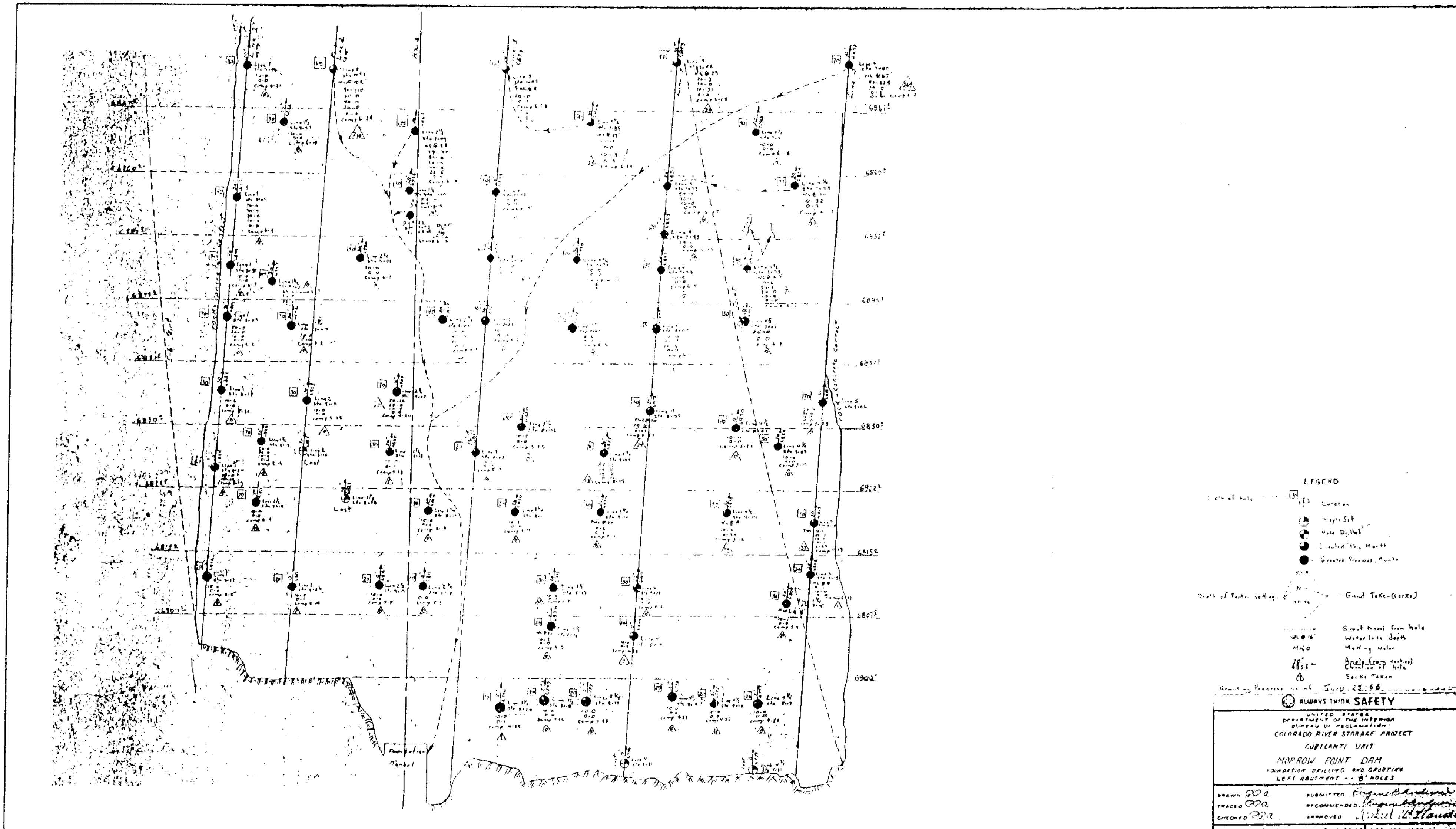
BUREAU OF RECLAMATION
COLORADO RIVER STORAGE PROJECT
CURECANTI UNIT
MORROW POINT DAM
FOUNDATION DRILLING AND GROUTING
LEFT ABUTMENT
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
CIMARRON, COLORADO


LEGEND
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER STORAGE PROJECT
CURECANTI UNIT
MORROW POINT DAM
FOUNDATION DRILLING AND GROUTING
LEFT ABUTMENT-- "B" HOLES
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
CIMARRON, COLO
Block 5
Block 4



LEGEND
Grout Take-(Sacks)
Grout travel from hole
Water loss depth
Making water
Sacks Taken
ALWAYS THINK SAFETY
UNITED STATES
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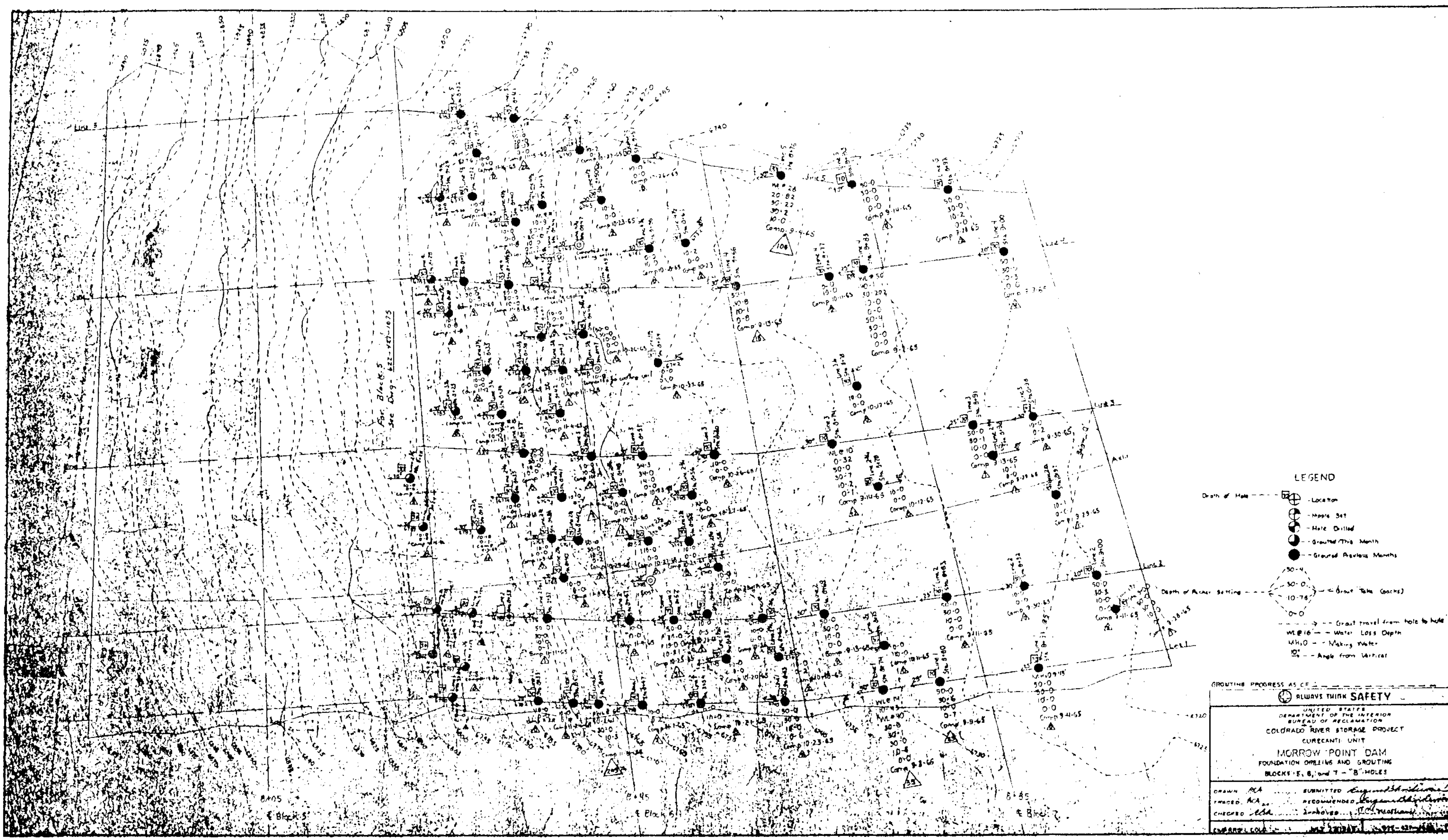
COLORADO RIVER STORAGE PROJECT
CURECANTI UNIT
MORROW POINT DAM
FOUNDATION DRILLING AND GROUTING
LEFT ABUTMENT -- "B" HOLES
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
CIMARRON, COLO


LEGEND
Depth of Hole
- Location
- Nipple Set
- Hole Drilled
- Grouted This Month
- Grouted Previous Months
Depth of Packer Setting
Grout Take (sacks)
Grout travel from hole to hole
WL@16 - Water Loss Depth
MH2O - Making Water
Angle from Vertical
GROUTING PROGRESS AS OF
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
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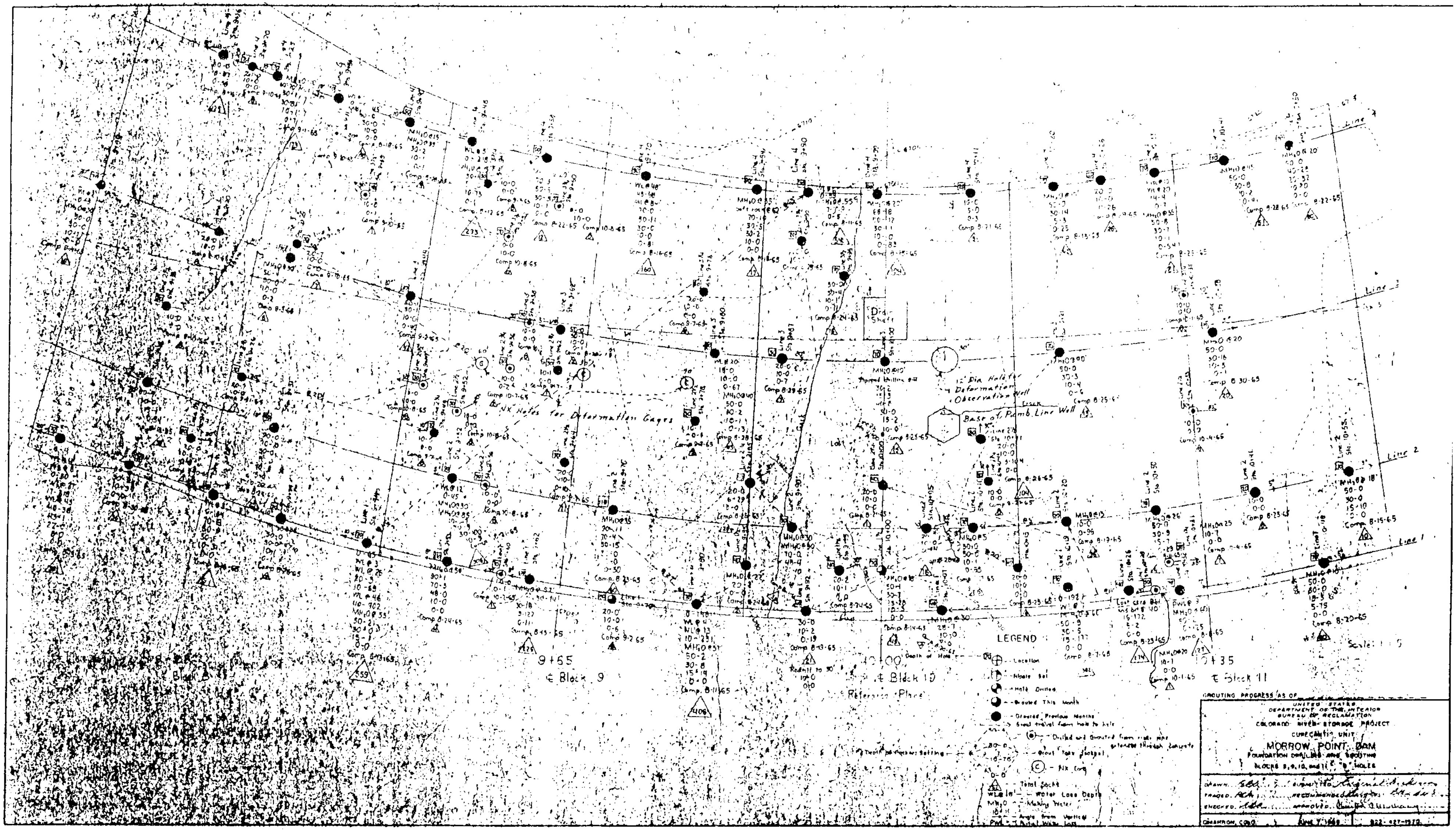
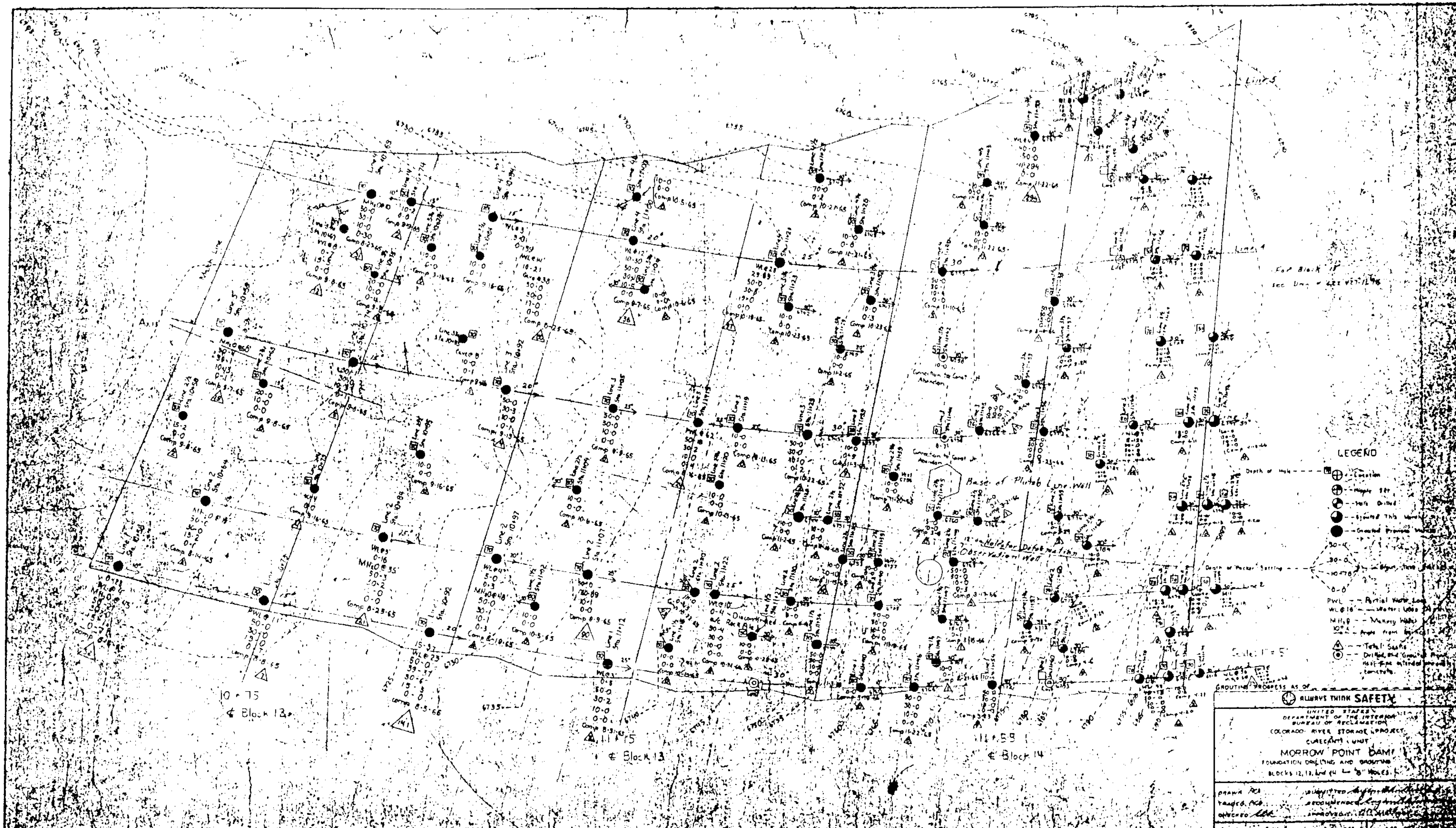
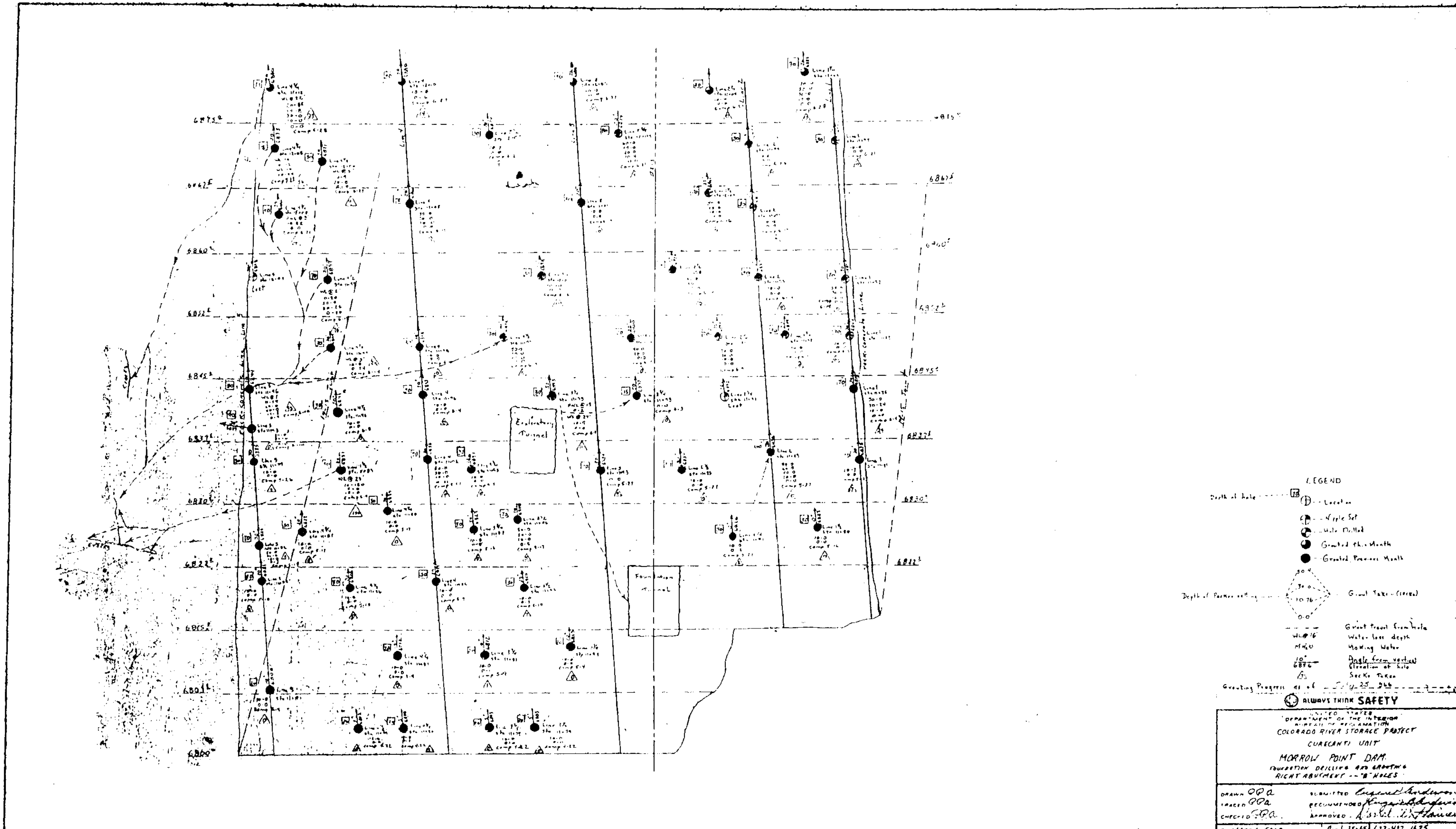
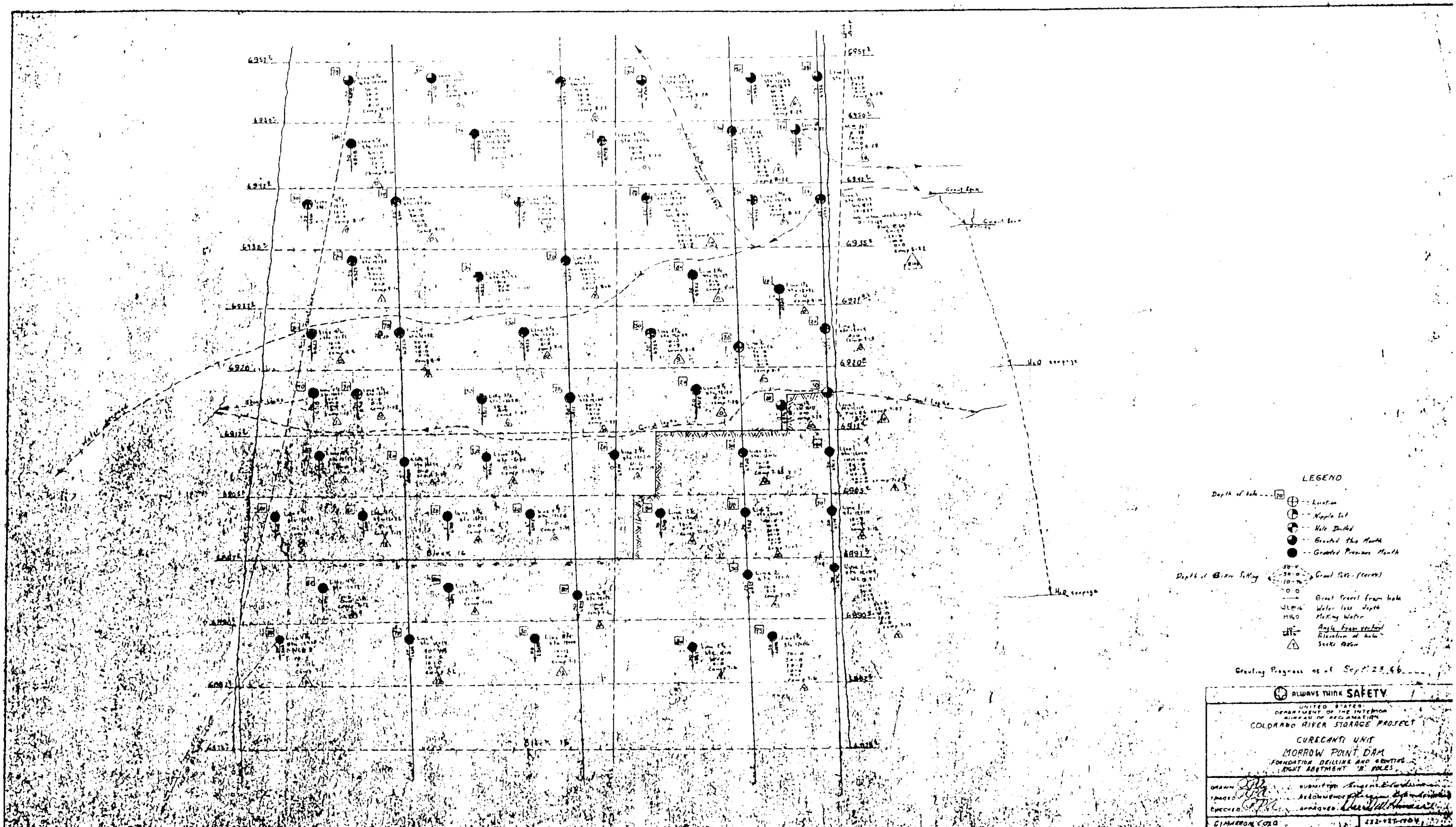
COLORADO RIVER STORAGE PROJECT
CURECANTI UNIT
MORROW POINT DAM
FOUNDATION DRILLING AND GROUTING
BLOCKS 5, 6, and 7 - "B" HOLES
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
Block 5
Block 6
Block 7



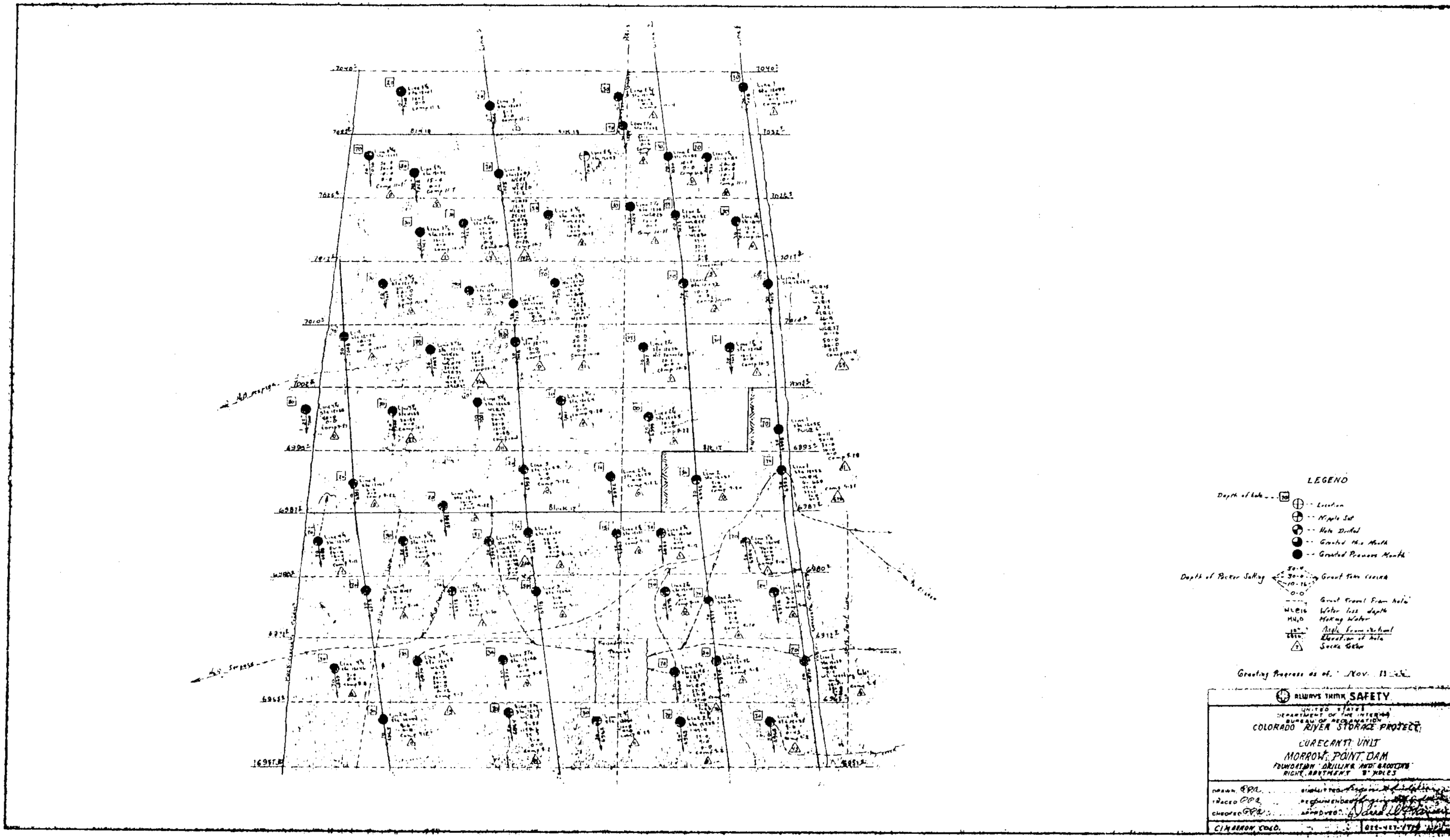
9+65
℄ Block 9
10+00
℄ Block 10
12+35
℄ Block 11
Reference Plane
NX Holes for Deformation Gages
12" Dia Hole for Deformation Observation Well
Base of Plumb Line Well
Line 1
Line 2
LEGEND
GROUTING PROGRESS AS OF
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER STORAGE PROJECT
CURECANTI UNIT
MORROW POINT DAM

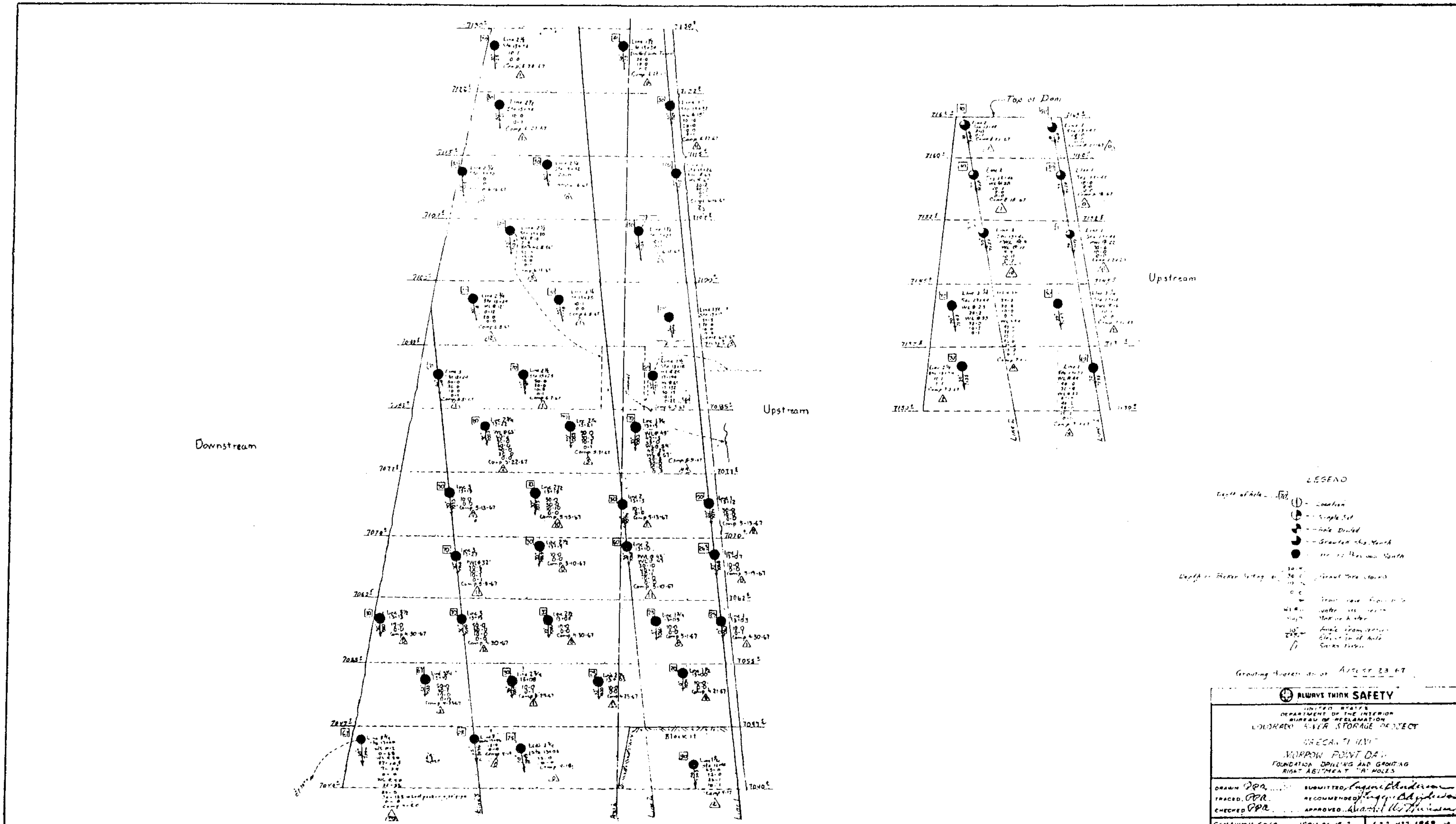

LEGEND
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER STORAGE PROJECT
CURECANTI UNIT
MORROW POINT DAM
FOUNDATION DRILLING AND GROUTING
Scale: 1" = 5'
10 + 75
℄ Block 13
11 + 15
℄ Block 13
11 + 55
℄ Block 14


LEGEND
Location
Nipple Set
Hole Drilled
Grouted this Month
Grouted Previous Month
Grout Take - (sacks)
Grout travel from hole
Water loss depth
Moving Water
Angle from vertical
Elevation of hole
Sacks Taken
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER STORAGE PROJECT
CURECANTI UNIT
MORROW POINT DAM
FOUNDATION DRILLING AND GROUTING
RIGHT ABUTMENT -- "B" HOLES
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
CIMARRON, COLO
April 25-65
622-427 1675

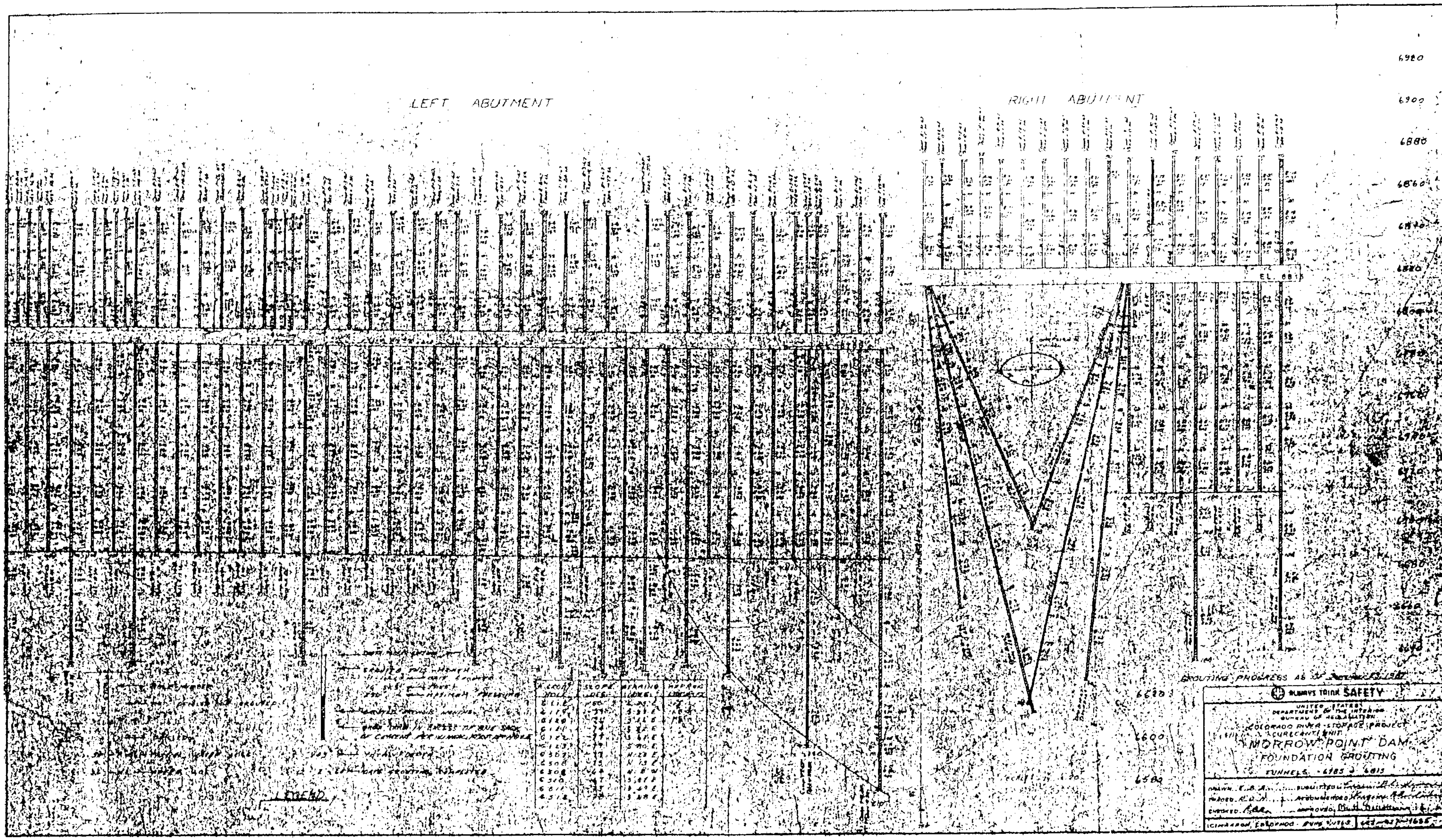


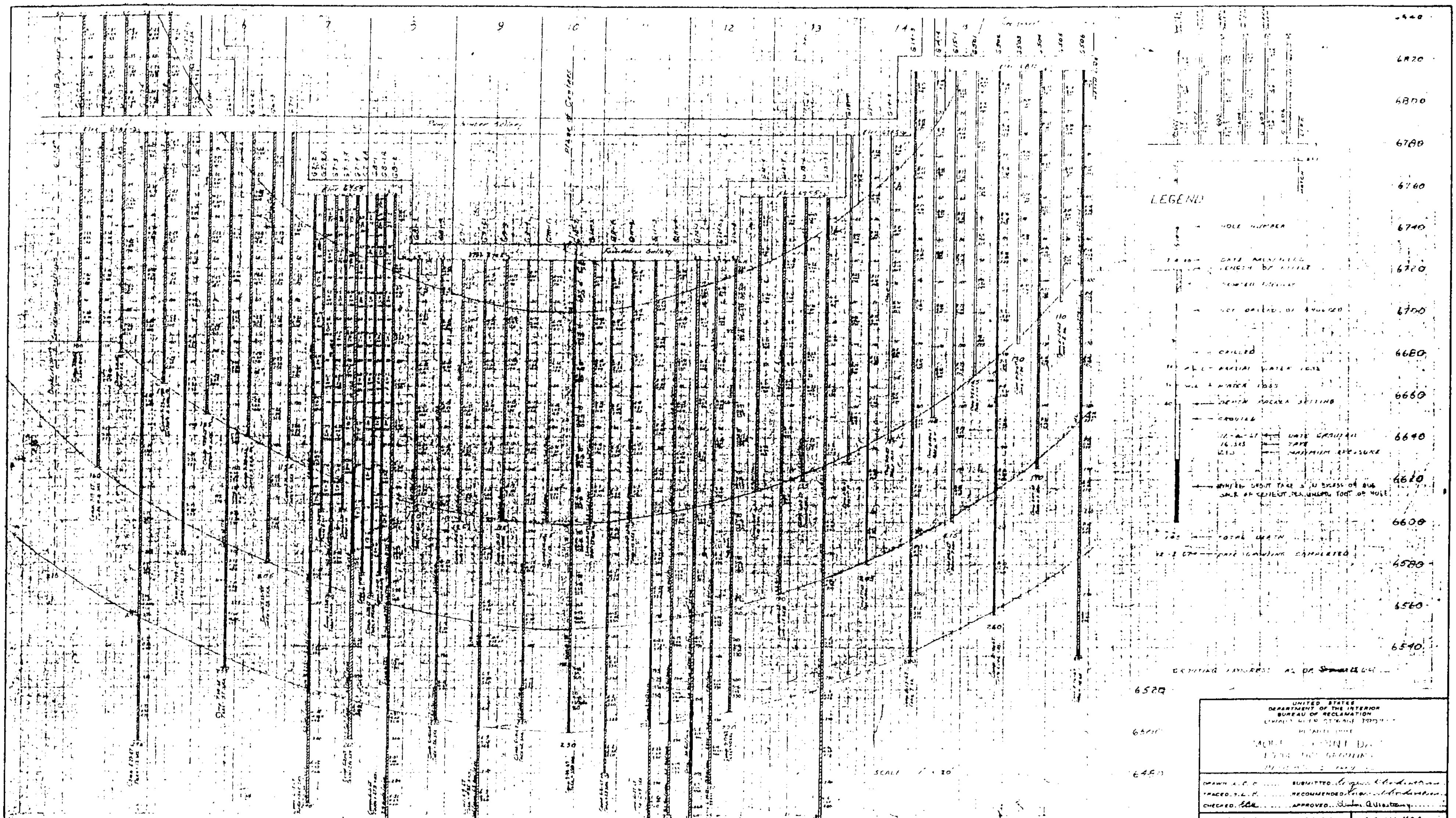
LEGEND
Depth of hole
Location
Nipple Set
Hole Drilled
Grouted This Month
Grouted Previous Month
Depth of Baker Setting
Grout Take (Sacks)
Grout Travel from hole
Water loss depth
Moving Water
Angle from vertical
Elevation of hole
Sacks Taken
Grouting Progress as of Sept. 23, 66
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER STORAGE PROJECT
CURECANTI UNIT
MORROW POINT DAM
FOUNDATION DRILLING AND GROUTING
RIGHT ABUTMENT "B" HOLES
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
CIMARRON, COLO.
Block 16
Block 15

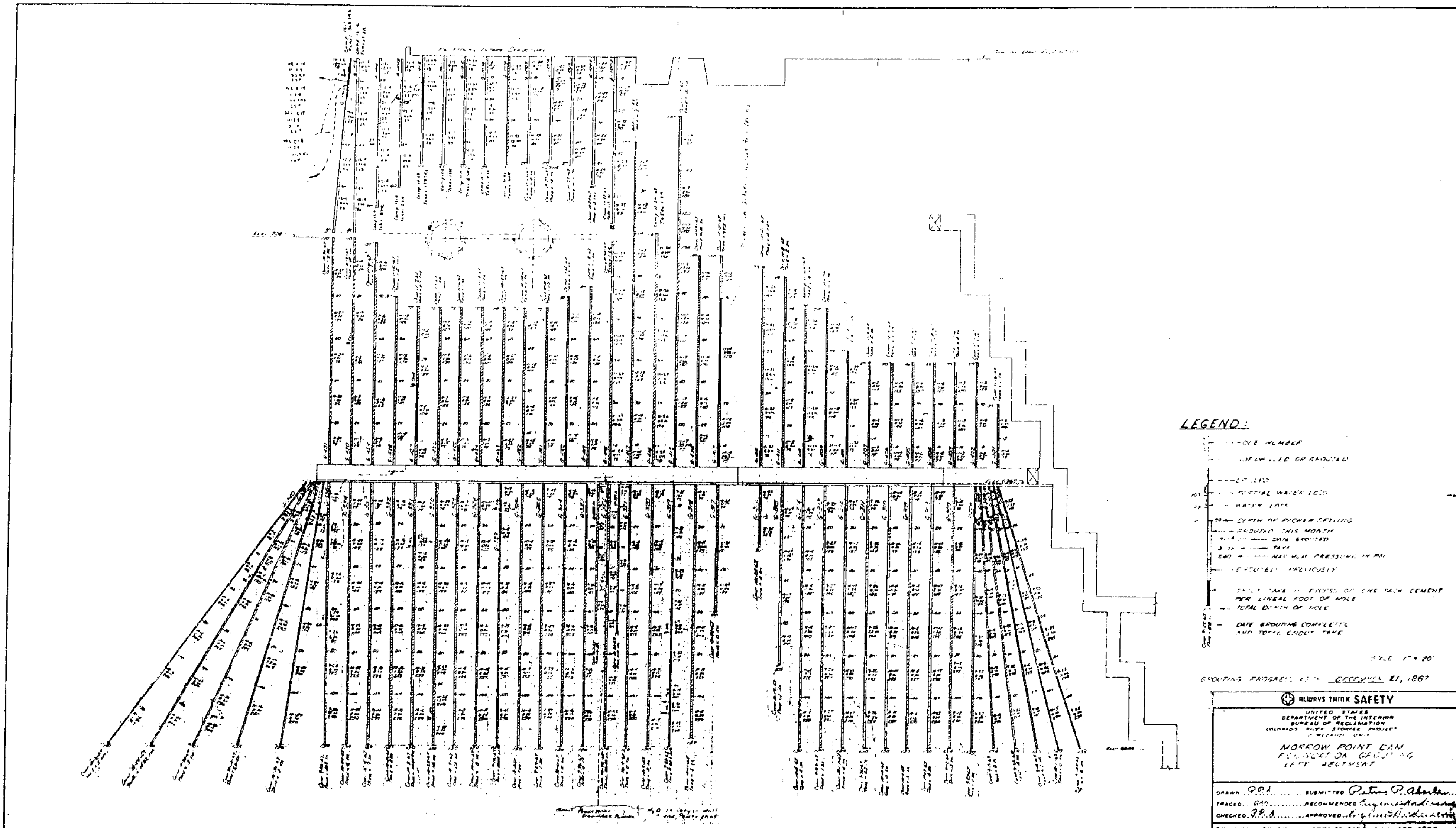

LEGEND
Depth of hole
Location
Nipple Set
Hole Drilled
Grouted this Month
Grouted Previous Month
Depth of Packer Setting
Grout Take (sacks)
Grout Travel From hole
Water loss depth
Making Water
Angle from vertical
Elevation of hole
Sacks Taken
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER STORAGE PROJECT
CURECANTI UNIT
MORROW POINT DAM
FOUNDATION DRILLING AND GROUTING
RIGHT ABUTMENT "B" HOLES
DRAWN
TRACED
CHECKED
RECOMMENDED
APPROVED
CIMARRON, COLO.

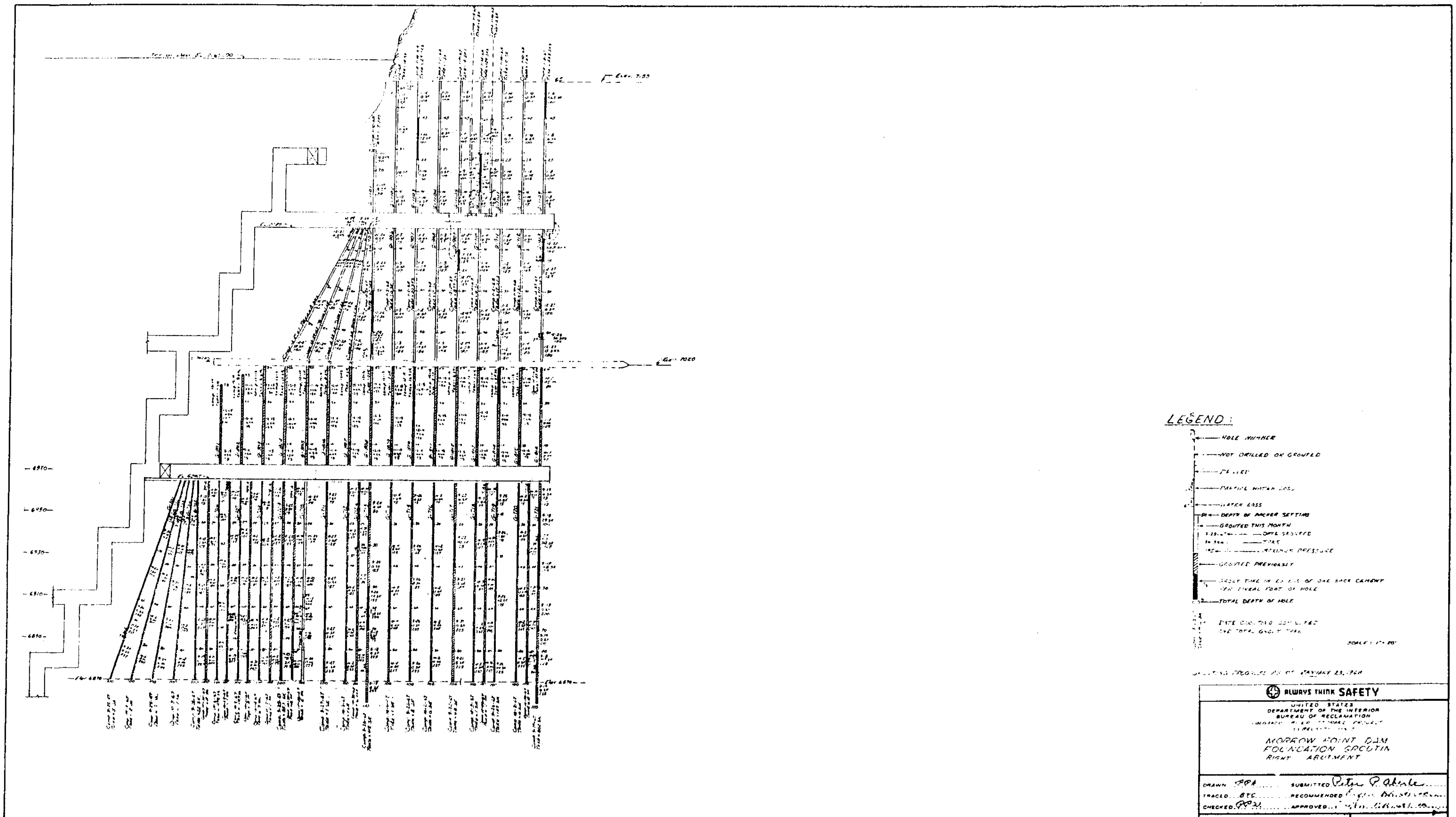


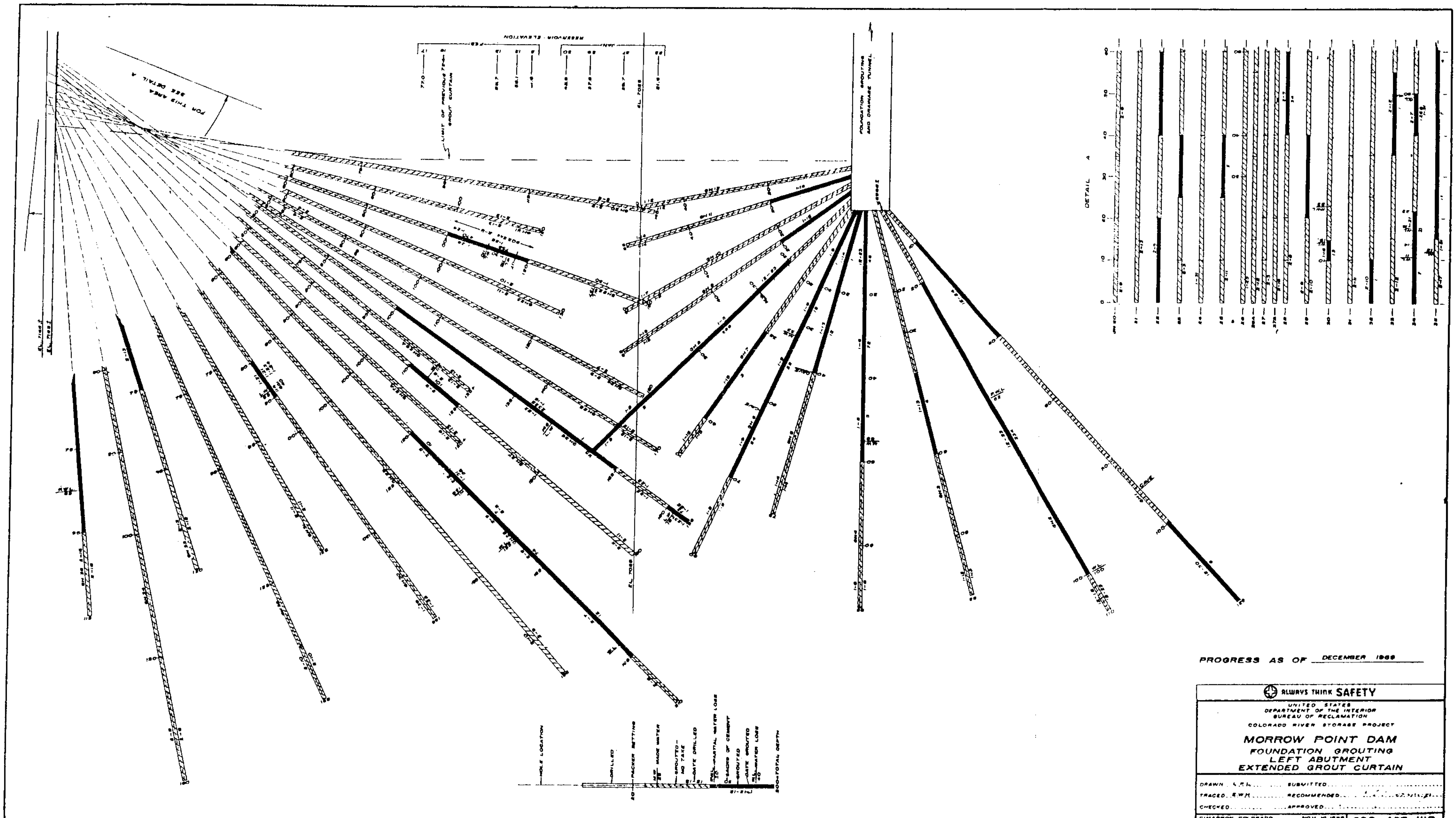
Downstream
Upstream
Top of Dam
Upstream
LEGEND
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
FOUNDATION DRILLING AND GROUTING
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
622 427-1849


LEFT ABUTMENT
6920
6900
6880
LEGEND
ALWAYS THINK SAFETY
MORROW POINT DAM
FOUNDATION GROUTING


LEGEND
HOLE NUMBER
6780
6760
6740
6720
6700
6680
6660
6640
6620
6600
6580
6560
6540
6520
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED


LEGEND:
HOLE NUMBER
WATER LOSS
DEPTH OF PACKER SETTING
GROUTED THIS MONTH
DATE GROUTED
TAKE
MAXIMUM PRESSURE IN PSI
GROUTED PREVIOUSLY
PER LINEAL FOOT OF HOLE
TOTAL DEPTH OF HOLE
DATE GROUTING COMPLETED
AND TOTAL GROUT TAKE
1" = 20'
GROUTING PROGRESS AS OF DECEMBER 21, 1967
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MORROW POINT DAM
LEFT ABUTMENT
DRAWN
SUBMITTED
TRACED
RECOMMENDED
CHECKED
APPROVED
SEPT. 29, 1967
1896


LEGEND:
HOLE NUMBER
NOT DRILLED OR GROUTED
DEPTH OF PACKER SETTING
GROUTED THIS MONTH
MAXIMUM PRESSURE
GROUTED PREVIOUSLY
TOTAL DEPTH OF HOLE
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MORROW POINT DAM
FOUNDATION GROUTING
RIGHT ABUTMENT
DRAWN
SUBMITTED
TRACED
RECOMMENDED
CHECKED
APPROVED
OCT. 12, 1967


FOUNDATION GROUTING AND DRAINAGE TUNNEL
LIMIT OF PREVIOUS GROUT CURTAIN
RESERVOIR ELEVATION
FOR THIS AREA SEE DETAIL A
DETAIL A
HOLE LOCATION
DRILLED
PACKER SETTING
MADE WATER
GROUTED-NO TAKE
DATE DRILLED
PARTIAL WATER LOSS
SACKS OF CEMENT
GROUTED
DATE GROUTED
WATER LOSS
TOTAL DEPTH
PROGRESS AS OF DECEMBER 1969
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER STORAGE PROJECT
MORROW POINT DAM
FOUNDATION GROUTING
LEFT ABUTMENT
EXTENDED GROUT CURTAIN
DRAWN
SUBMITTED
TRACED E.W.H.
RECOMMENDED
CHECKED
APPROVED
CIMARRON, COLORADO
622-427-1118

APPENDIX C

DOCUMENTS REVIEWED (not listed in Appendix A)
(Project titles abbreviated)

1. "Morrow Point Underground Powerplant Rock Mechanics Investigations", Bureau of Reclamation, Denver, Colorado, March 1967.

2. Technical Data Workbook, Morrow Point Dam, undated.

3. Final SEED Report, Morrow Point Dam, February 26, 1979.

4. Specifications No. DC-5915 Morrow Point Dam and Powerplant, "Pressure Grouting" and "Drainage", pp. 81-99.

5. Monthly Drilling and Grouting Operations (L-10) Reports, August, September, October, November 1965, April through November 1966, February 1967 through February 1968.

6. Final Construction Report, Morrow Point Dam and Powerplant, 1971; Foundation Grouting, Drilling and Drainage, pp. 396-411; Experimental Cationic Asphalt Emulsion Grouting, pp. 539-551 and pp. 635-636.

7. Cationic asphalt emulsion grouting of left abutment - six miscellaneous documents.

8. Memorandum dated July 22, 1965 from Field Engineer, Morrow Point, to Field Personnel, Morrow Point, subject: "Delineation of authority and responsibility among the various Field Force Branches".

9. Memorandum dated March 9, 1967 from E. B. Anderson to Grout Inspectors, subject: "Checking Gage Savers".

10. Memorandum dated August 15, 1966 from E. B. Anderson to Grout Inspectors, subject: "Preparation of Drilling and Grouting Reports".

11. Memorandum dated March 18, 1967 from E. B. Anderson to Grout Inspectors, subject: "Grout Holes Making Water".

12. Memorandum dated August 19, 1966 from E. B. Anderson to Grout Inspectors, subject: "Preparing and assembling drill and grout reports".

13. Memorandum dated June 17, 1966 from Chief, Grouting and Technical Installation Branch, to Chiefs of General Inspection Branches, subject: "Procedure for Checking Grout Systems".

14. Travel report dated April 20, 1967, from L. R. Gebhart, Engineer, to Chief Engineer, subject: "Foundation and contraction joint grouting, Morrow Point Dam".

15. Travel report dated December 11, 1967, from L. R. Gebhart to Chief Engineer, subject: "Foundation and contraction joint grouting, Morrow Point Dam".

16. Letter dated November 3, 1967 from Chief Engineer to Project Construction Engineer, Montrose, Colorado, subject: "'A' line grouting, Morrow Point Dam".

17. Letter dated November 1, 1967, from Acting Project Construction Engineer to Project Manager, Johnson,-M-K, subject: "'A' Line Grouting, Morrow Point Dam".

18. Letter dated October 16, 1967, from Chief Construction Engineer to Project Construction Engineer, Montrose, Colorado, subject: "Leakage between formed drains in Block 10 Morrow Point Dam".

19. Letter dated October 19, 1967 from Project Construction Engineer to Chief Engineer, subject: "Curtain Grouting, Morrow Point Dam".

20. Letter dated October 18, 1967, from Project Manager to Project Construction Engineer, subject: "Morrow Point Dam - "A" Hole Curtain Grouting".

21. Letter dated March 21, 1967 from Acting Chief Engineer to Project Construction Engineer, subject: "Drilling and Grouting Morrow Point Dam" (your letter dated March 8, 1967).

22. Letter dated March 8, 1967 from Project Construction Engineer to Chief Engineer, subject: "Drilling and grouting, Morrow Point Dam".

23. Letter dated December 15, 1966 from Acting Chief Engineer to Project Construction Engineer, subject: "Stilling Basin, Morrow Point Dam", (your letter dated December 2, 1966).

24. Travel report dated December 7, 1966, from L. R. Gebhart to Chief Engineer, subject: "Initial contraction joint grouting, Morrow Point Dam".

25. Letter dated April 26, 1966 from Project Construction Engineer to Project Manager, Johnson-M-K, subject: "Transmittal of Drawings, Morrow Point Dam".

26. Letter dated April 18, 1966, from Chief Construction Engineer to Project Construction Engineer, subject: "Transmittal of construction drawings, Morrow Point Dam".

27. Drain flows, Morrow Point Dam, 1980-1981.

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.

A free pamphlet is available from the Bureau entitled "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request from the Bureau of Reclamation, Attn D-822A, P O Box 25007, Denver Federal Center, Denver CO 80225-0007.