GR-86-7

ANALYSIS OF UTILIZATION OF GROUT AND GROUT CURTAINS — HERON DAM

February 1986
Engineering and Research Center

U.S. Department of the Interior
Bureau of Reclamation
Division of Research and
Laboratory Services
Concrete and Structural Branch

7-2090 (4-81)
Bureau of Reclamation

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. GR-86-7	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE Analysis of Utilization of Grout and Grout Curtains–Heron Dam		5. REPORT DATE February 1986
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Claude A. Fetzer		8. PERFORMING ORGANIZATION REPORT NO. GR-86-7
9. PERFORMING ORGANIZATION NAME AND ADDRESS		10. WORK UNIT NO.
		11. CONTRACT OR GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Bureau of Reclamation Engineering and Research Center Denver, Colorado 80225		13. TYPE OF REPORT AND PERIOD COVERED
		14. SPONSORING AGENCY CODE DIBR

15. SUPPLEMENTARY NOTES

JMT

16. ABSTRACT

The foundation grouting program at Heron 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.

17. KEY WORDS AND DOCUMENT ANALYSIS

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

b. *IDENTIFIERS--* Heron Dam/ New Mexico/ SW Region

c. *COSATI Field/Group* 08H *COWRR:* 0808 *SRIM:*

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (THIS REPORT) UNCLASSIFIED	21. NO. OF PAGES 203
	20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	22. PRICE

GR-86-7

ANALYSIS OF UTILIZATION OF GROUT AND GROUT CURTAINS– HERON DAM

by

Claude A. Fetzer

Prepared Under Contract No. 2-07-DV-00148

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

February 1986

UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

ACKNOWLEDGMENT

This report was prepared for the Bureau of Reclamation under contract with Claude A. Fetzer and was under the jurisdiction of W. Glenn Smoak, Principal Investigator, Concrete and Structural Branch, Division of Research and Laboratory Services.

This report was published in the GR series from a copy of the report provided by the contractor, thus, the quality of photographs and figures may be less than usually acceptable.

The research covered by this report was funded under the Bureau of Reclamation PRESS (Program Related Engineering and Scientific Studies) allocation No. DF-12, Portland Cement Grouting Program.

ANALYSIS OF UTILIZATION OF GROUT AND GROUT CURTAINS

HERON DAM

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ANALYSIS OF THE UTILIZATION OF GROUT AND GROUT CURTAINS

HERON DAM

I. INTRODUCTION

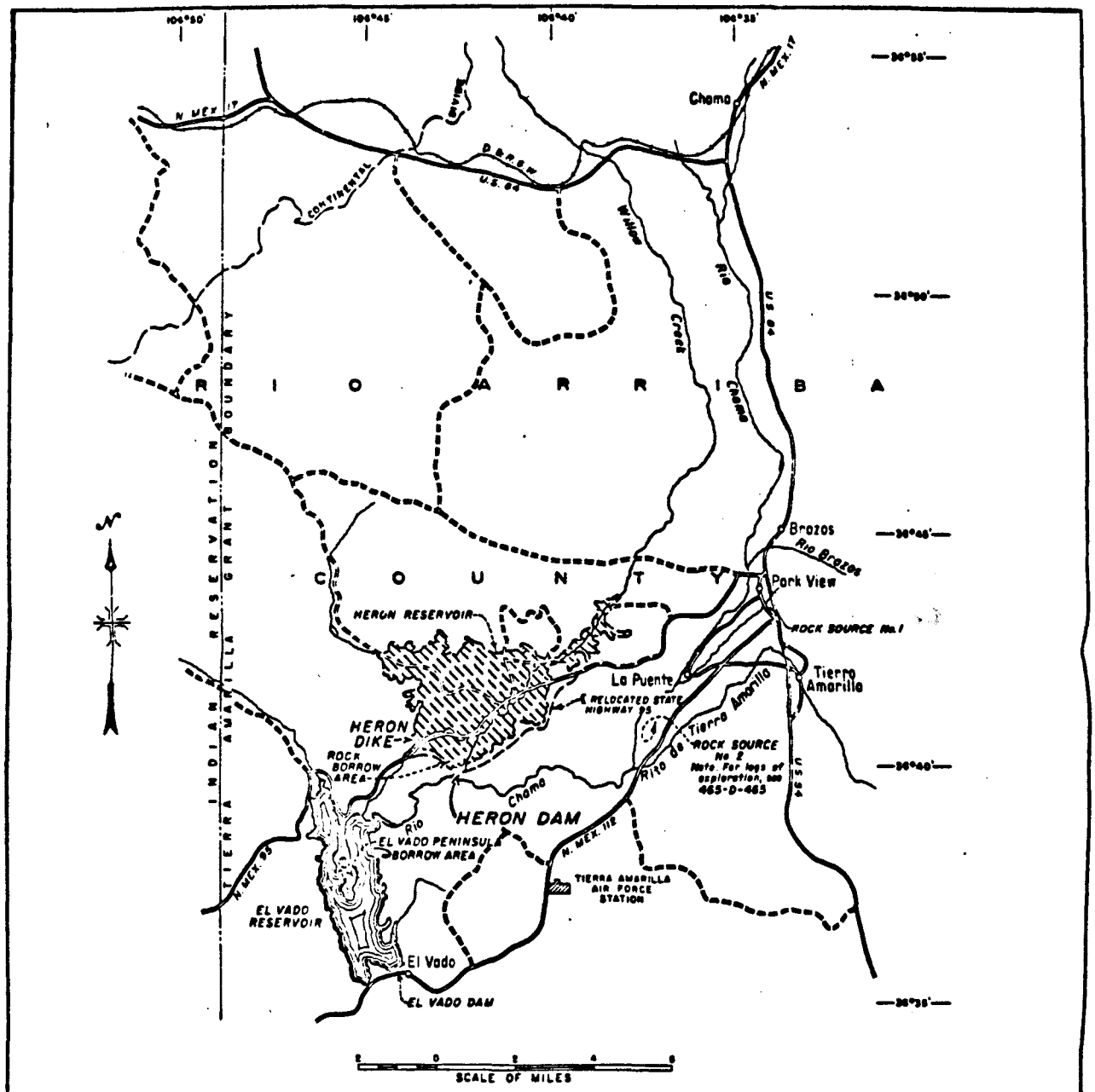
1. General description. Heron Dam is part of the Colorado-New Mexico San Juan-Chama Project. The dam is located in north central New Mexico about 9 miles southwest of Tierra Amarilla, New Mexico. See figure 1.

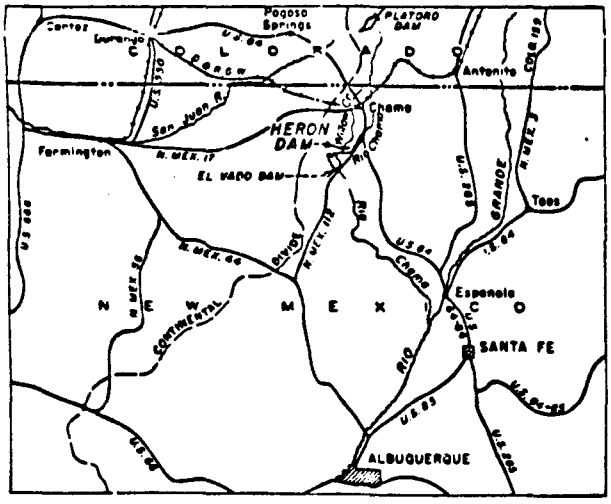
The main dam is located on Willow Creek just above the confluence of Willow Creek and the Chama River, and the closure dike is located about 1-1/2 miles west of the dam. The main dam is a zoned earth and rockfill structure having a maximum structural height of 274 feet. The crest is at El. 7,199 feet and has a length of 1,220 feet and a width of 40 feet. An aerial view of the dam is shown on figure 2.

The closure dike is a zoned earth and rockfill structure having a maximum structural height of 94 feet. The crest length is 2,405 feet and the crest width is 30 feet. An aerial view of the dike is shown on figure 3.

The reservoir receives water diverted from the San Juan River System and has a maximum capacity of 428,310 ac.ft. at El. 7,190.8 feet. The reservoir is designed to operate at El. 7,186.1 with a storage capacity of 399,980 ac.ft.

Construction of the dam and dike was started in 1967 and the work was completed in 1971.





KEY MAP

8-3-67 8-7-68	REVISED LOCATION OF ROCK SOURCE No. 1

ALWAYS THINK SAFETY

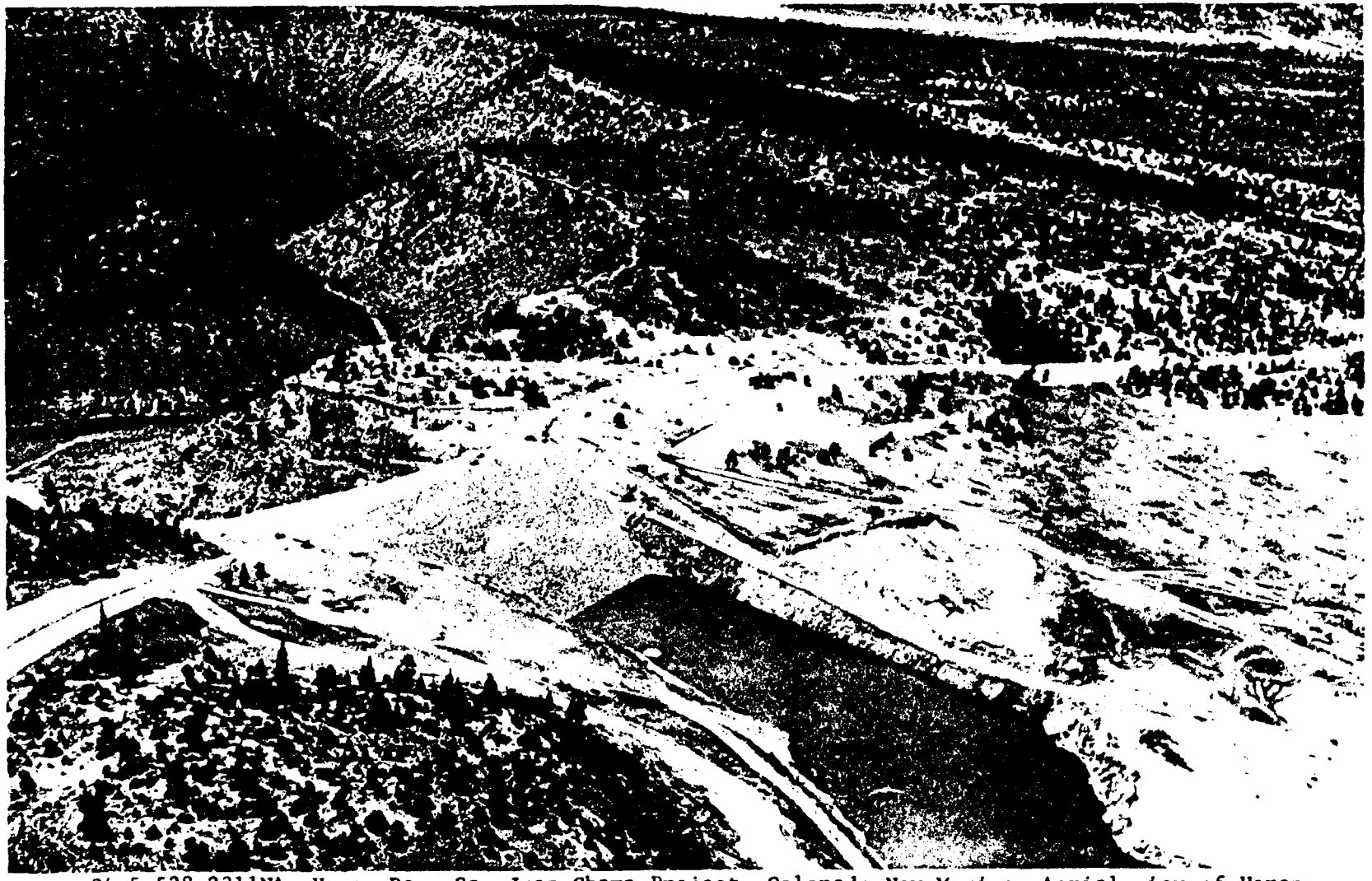
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN-CHAMA PROJECT, COLORADO-NEW MEXICO

HERON DAM
LOCATION MAP

DRAWN L.E.C. SUBMITTED R. J. Larsen
TRACED R.L.S. RECOMMENDED H. G. Arthur
CHECKED R.C.W. APPROVED A. A. Burkart
CHIEF ENGINEER

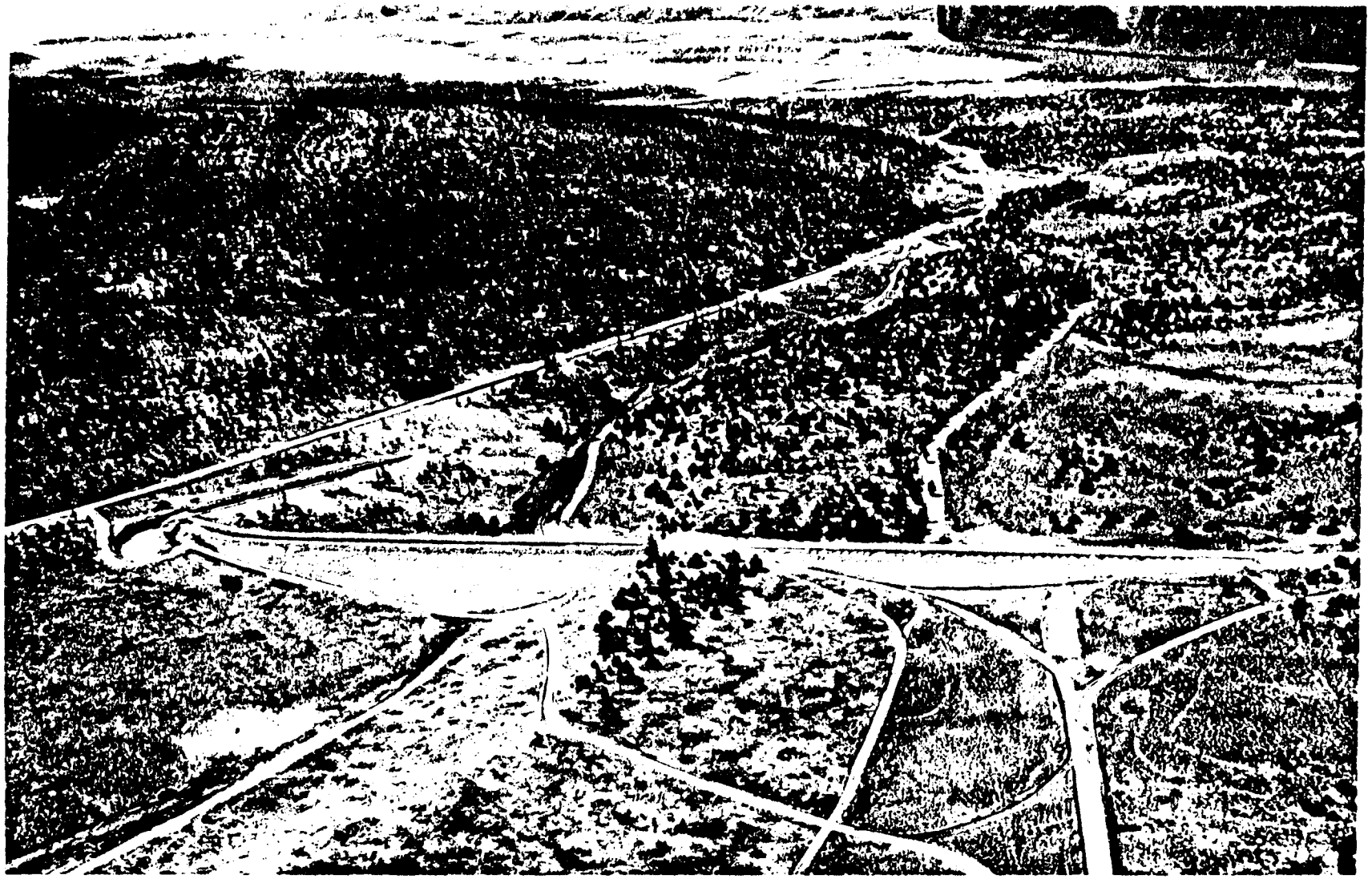
DENVER, COLORADO, MAY 31, 1966 — 465-D-468

FIGURE 1



P465-528-2811NA Heron Dam--San Juan-Chama Project--Colorado-New Mexico Aerial view of Heron Dam taken looking southwest. The dam embankment is completed to the crest elevation. The relocated Highway #95 can be seen crossing the dam. The reservoir upstream of the dam is at elevation 7051. The top of the outlet works intake structure can be seen in the lower center of the photo. Work is underway on the riprap and shaping of the slopes of the upper part of the dam.
Specifications No. DC-6558 Universal Constructors, Inc.
5-19-71 **Bureau of Reclamation Photo by D. Manning**

Figure 2



P465-528-2619NA Heron Dam and Relocation of State Highway No. 95--San Juan-Chama Project--Colorado-New Mexico An aerial view of Heron Dike looking southwest toward El Vado Reservoir, which is visible in the upper left portion of the photo. The newly relocated State Highway No. 95 is visible in the center left above the spillway. The State of New Mexico will pave State Highway 95 after completion of Heron Dam construction.
Specifications No. DC-6558 Universal Constructors, Inc.
8-3-70 Bureau of Reclamation Photo by D. Manning

Figure 3

The general plan and sections for the Heron Dam are shown on figure 4. The outlet works consisting of an intake structure, a horse-shoe tunnel, a shaft house and gate chamber, and an outlet structure are located in the left abutment of the dam; the plan and sections are shown on figure 5. The general plan and sections of Heron Dike are shown on figure 6. The spillway is located at the left end of the dike and consists of a 40-foot-wide paved channel with vertical side walls; the plan and sections are shown on figure 7.

2. Heron Dam. Heron Dam has a wide central impervious core flanked by sand and gravel and rockfill shells as described on figure 4. A 200-foot-wide cutoff to rock was provided beneath the impervious core. The centerline of the cutoff followed the axis of the dam on the upper parts of the abutments but was shifted about 75 feet upstream of the dam axis in the valley bottom. The excavation for the cutoff trench was notched into the abutments to form a uniform slope of about 35 degrees from the horizontal as shown on figure 4. The rock surface in the valley bottom was thoroughly cleaned, but there is no indication that the cutoff was notched into the rock.

A 3-line grout curtain was provided in the plans and specifications along the centerline of the cutoff trench from Station 9+50 to Station 19+20 - that is from the top of the right abutment to the top of the left abutment. However, the downstream line was not installed during construction, and the upstream line was only installed across the valley bottom and part way up the abutments. A concrete grout cap having a width of about 3 feet and a depth

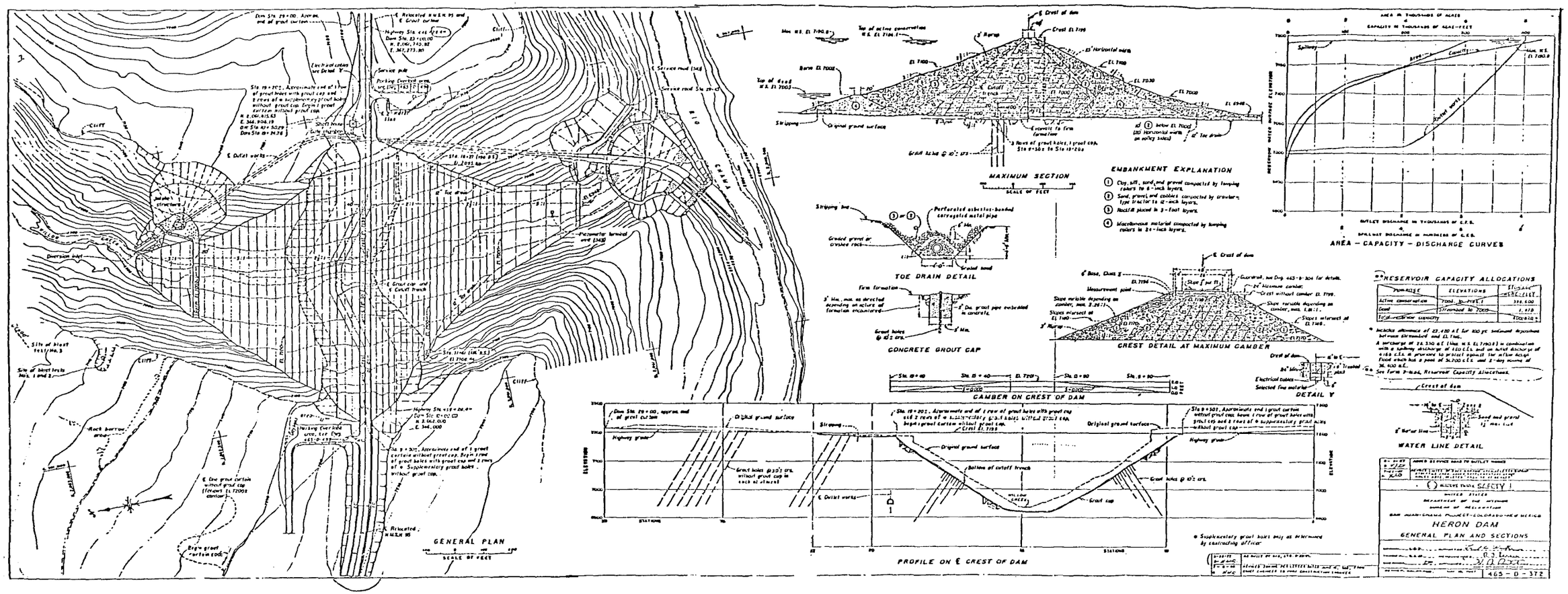
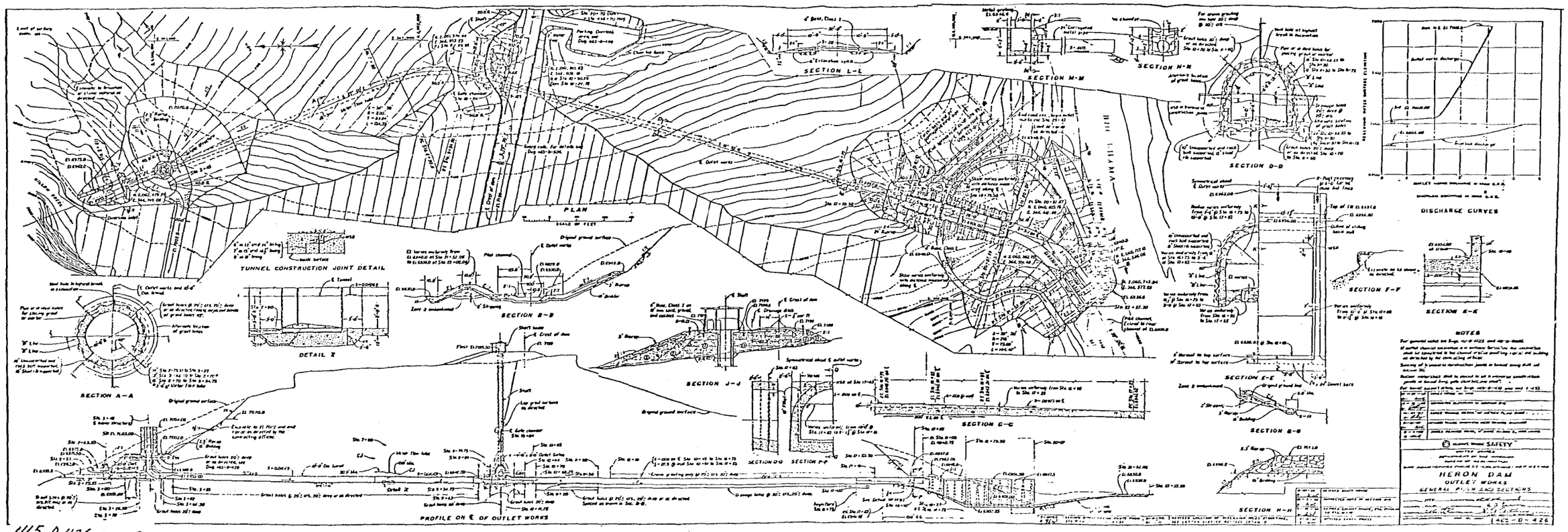

GENERAL PLAN
SCALE OF FEET
MAXIMUM SECTION
EMBANKMENT EXPLANATION
TOE DRAIN DETAIL
CONCRETE GROUT CAP
CREST DETAIL AT MAXIMUM CAMBER
CAMBER ON CREST OF DAM
DETAIL Y
PROFILE ON ℄ CREST OF DAM
AREA - CAPACITY - DISCHARGE CURVES
RESERVOIR CAPACITY ALLOCATIONS
WATER LINE DETAIL
HERON DAM
GENERAL PLAN AND SECTIONS
465-D-372

FIGURE 4



465-D-426 FRAME 2

FIGURE 8

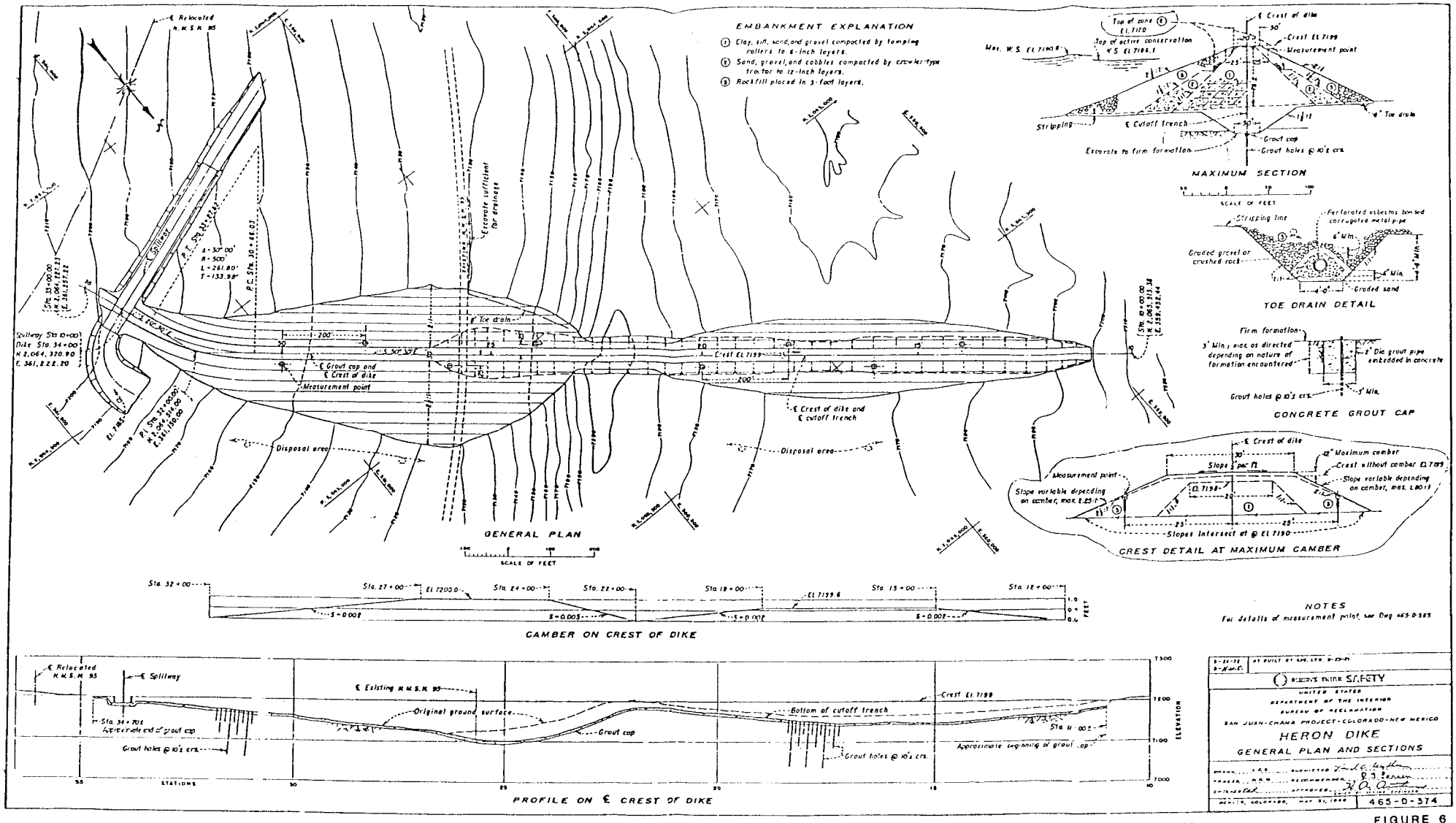
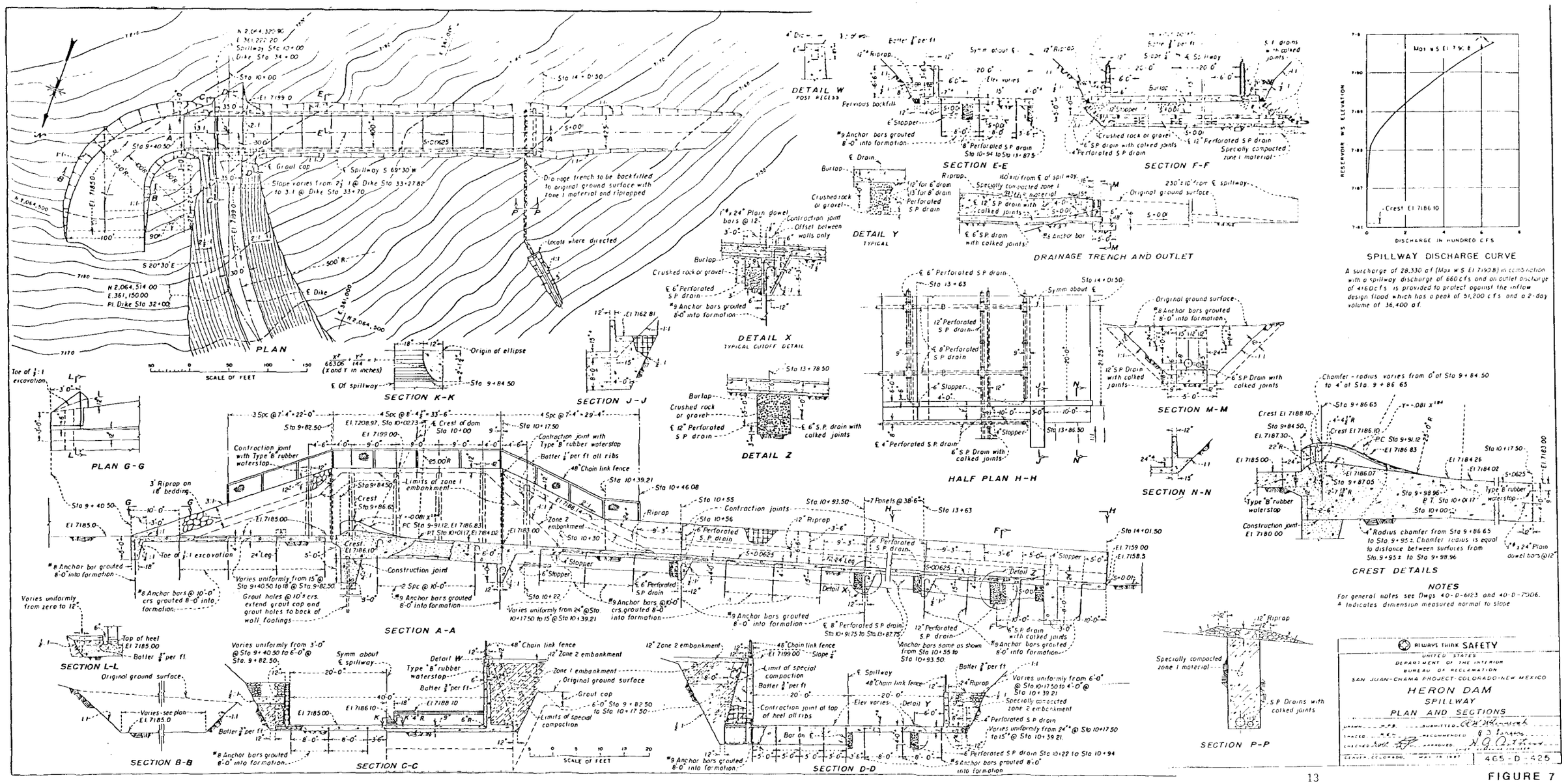

EMBANKMENT EXPLANATION
(1) Clay, silt, sand, and gravel compacted by tamping rollers to 6-inch layers.
(2) Sand, gravel, and cobbles compacted by crawler-type tractor to 12-inch layers.
(3) Rockfill placed in 3-foot layers.
GENERAL PLAN
SCALE OF FEET
Spillway
Relocated K.M.S.K. 95
Excavate sufficient for drainage
Toe drain
Grout cap and ℄ Crest of dike
Measurement point
℄ Crest EL 7199
℄ Crest of dike and ℄ cutoff trench
Disposal area
Spillway Sta 10+00
Dike Sta 34+00
N 2,064,320.90
E 361,222.20
EL 7185
MAXIMUM SECTION
Top of zone (1) EL 7170
Top of active conservation W.S. EL 7186.1
Max. W.S. EL 7190.8
℄ Crest of dike
Crest EL 7199
Measurement point
Stripping
℄ Cutoff trench
Excavate to firm formation
Grout cap
Grout holes @ 10'± crs.
4" Toe drain
TOE DRAIN DETAIL
Stripping line
Perforated asbestos bonded corrugated metal pipe
Graded gravel or crushed rock
Graded sand
CONCRETE GROUT CAP
Firm formation
3' Min.; pick as directed depending on nature of formation encountered
2" Dia. grout pipe embedded in concrete
Grout holes @ 10'± crs.
CREST DETAIL AT MAXIMUM CAMBER
℄ Crest of dike
Maximum camber
Crest without camber EL 7189
Slope variable depending on camber, max. 1.8:1
Slopes intersect at @ EL 7190
CAMBER ON CREST OF DIKE
Sta. 32+00
Sta. 27+00
EL 7200.0
Sta. 24+00
Sta. 22+00
Sta. 19+00
EL 7199.6
Sta. 15+00
Sta. 12+00
S = 0.00%
S = 0.005
S = 0.00%
S = 0.00%
PROFILE ON ℄ CREST OF DIKE
℄ Existing K.M.S.K. 95
Original ground surface
Bottom of cutoff trench
Crest EL 7199
Grout cap
Grout holes @ 10'± crs.
Approximate beginning of grout cap
Approximate end of grout cap
Sta. 34+70±
Sta. 11+00±
STATIONS
ELEVATION
NOTES
For details of measurement point, see Dwg 465-D-585
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN-CHAMA PROJECT-COLORADO-NEW MEXICO
HERON DIKE
GENERAL PLAN AND SECTIONS
465-D-374

FIGURE 6



A surcharge of 28,330 af (Max W S El 7198.8) in combination with a spillway discharge of 660 cfs and an outlet discharge of 4160 cfs is provided to protect against the inflow design flood which has a peak of 51,200 cfs and a 2-day volume of 36,400 af.

NOTES

For general notes see Dwgs 40-D-6123 and 40-D-7506.
A indicates dimension measured normal to slope

FIGURE 7

ranging from 3 feet to 6 feet into the finished rock surface was provided for the center line of grout holes. Blanket grouting was also provided where the condition of the rock indicated consolidation grouting was needed before the curtain grouting could be initiated. The grout curtain was extended 1,000 feet on both sides of the dam. The extended curtain consisted of a single line without a grout cap.

The dam has a 10-foot-thick drainage blanket extending from the impervious core to the downstream toe. A 12-inch-diameter perforated collector pipe was provided on each abutment beneath the drainage blanket near the embankment-abutment contact. The pipes start on each abutment about El. 7,100 feet and run to the downstream toe where they discharge into the outlet works retreat channel.

Thirty double-tube piezometers were installed to measure uplift pressures in the rock, and seepage and pore pressure in the embankment. Nine piezometers were installed in the foundation, and 21 piezometers were installed in the embankment. All of the piezometers were installed in the bottom of the valley between Stations 14+00 and 16+00. See figure 8.

3. Heron Dike. Heron Dike has a wide central impervious core flanked by sand and gravel and rock shells as shown on figure 6. A 30-foot-wide cutoff trench was excavated through overburden and highly weathered rock to firm rock from Station 10+00 to Station 26+00. Side slopes of the cutoff trench were 1 vertical on 1-1/2 horizontal. Between Station 26+00 and the left end of the dike (Station 33+80), firm rock was exposed at the

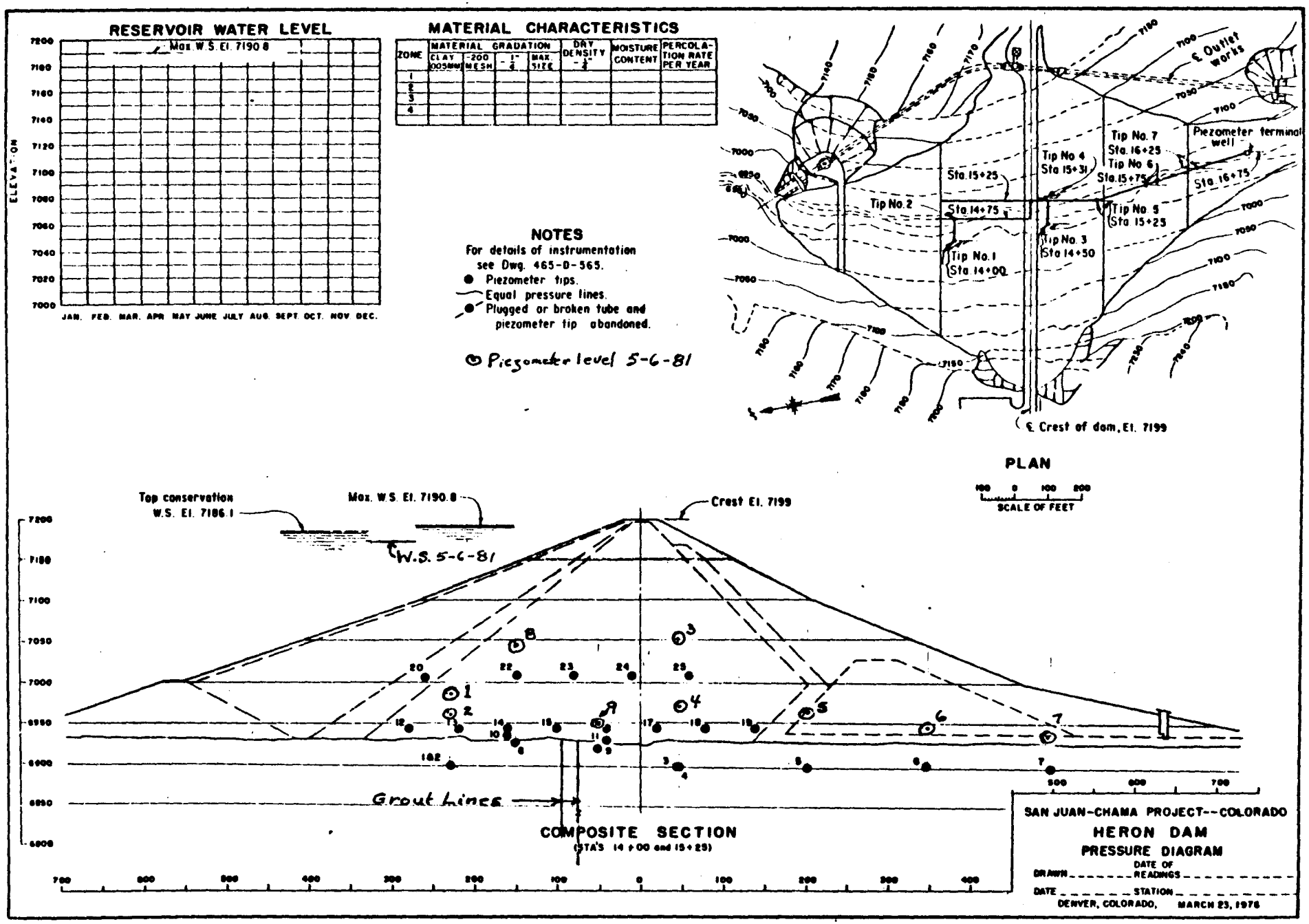

RESERVOIR WATER LEVEL
Max. W.S. El. 7190.8
ELEVATION
7200
7180
7160
7140
7120
7100
7080
7060
7040
7020
7000
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.
MATERIAL CHARACTERISTICS
ZONE
MATERIAL GRADATION
CLAY .005MM
-200 MESH
1" - 4
MAX. SIZE
DRY DENSITY - 4"
MOISTURE CONTENT
PERCOLATION RATE PER YEAR
1
2
3
4
NOTES
For details of instrumentation see Dwg. 465-D-565.
Piezometer tips.
Equal pressure lines.
Plugged or broken tube and piezometer tip abandoned.
Piezometer level 5-6-81
℄ Outlet works
Piezometer terminal well
Tip No. 7 Sta. 16+25
Tip No 6 Sta. 15+75
Tip No 4 Sta 15+31
Sta. 15+25
Tip No. 2
Sta. 14+75
Tip No. 5 Sta 15+25
Tip No. 3 Sta 14+50
Tip No. 1 Sta. 14+00
Sta. 16+75
℄ Crest of dam, El. 7199
PLAN
SCALE OF FEET
Top conservation W.S. El. 7186.1
Max. W.S. El. 7190.8
Crest El. 7199
W.S. 5-6-81
Grout lines
COMPOSITE SECTION
(STA'S 14+00 and 15+25)
SAN JUAN-CHAMA PROJECT--COLORADO
HERON DAM
PRESSURE DIAGRAM
DRAWN
DATE OF READINGS
DATE
STATION
DENVER, COLORADO, MARCH 23, 1976

FIGURE 8

surface and the entire impervious core was founded directly on the bedrock. A single-line grout curtain was provided from Station 10+79 to Station 34+69 with the curtain extending across the spillway at the left end of the dike. Grouting was accomplished through a concrete grout cap with a width of 3 feet and a minimum depth of 3 feet. Blanket grouting was provided for a relief crack that developed along the right side of the spillway excavation.

An 8-inch-diameter perforated toe drain was provided beneath the dike embankment near the embankment-abutment contact, where an intermediate ridge existed. The toe drain started about El. 7,170 feet and ran to the bottom of the valley where it discharged along side of abandoned U.S. Highway 95. No piezometers were provided for the dike.

II. GEOLOGY

4. Regional geology. Heron Dam is located about 25 miles southwest of Chama, New Mexico in the San Juan Mountains. Sedimentary rocks of the Jurassic and Upper Cretaceous Age capped by extrusive rocks and unconsolidated sediments of Quaternary Age make up the rock sequence in the vicinity of the dam. See figure 9. Structural features of the region are complex and are best shown on figure 10. The dam was constructed on the northeast flank of North El Vado Dome, also shown on figure 10.

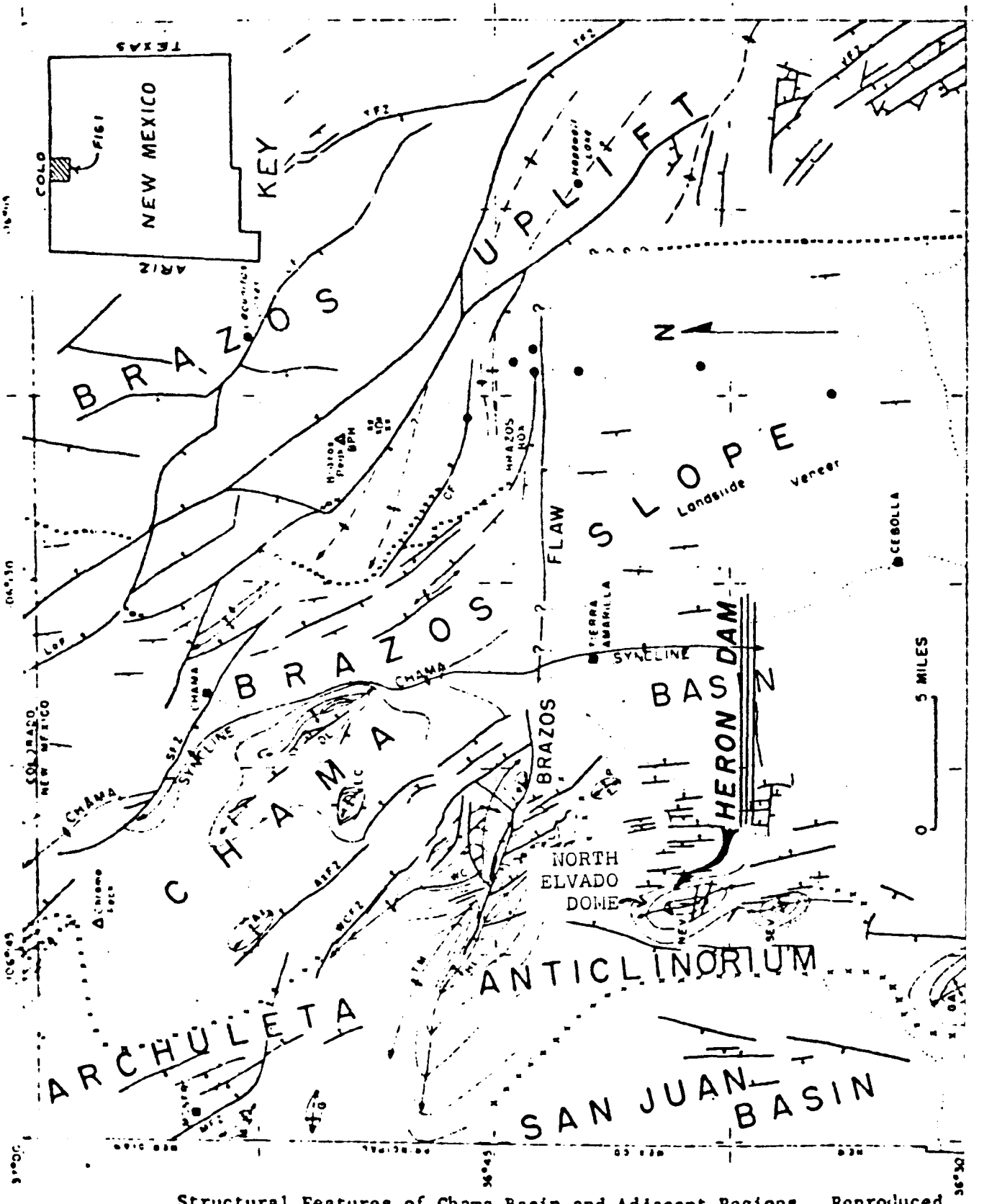
Topography in the vicinity of Heron Dam is characterized by steep-walled canyons where the Chama River and Willow Creek have eroded deep channels in sandstone of the Dakota and Morrison formations. Elsewhere the topography is characterized by gently rolling hills and broad valleys typical of normal weathering and erosion of the Mancos formation. Low ridges are formed by more resistant beds in the shale formation. Several structural and topographic domes with dip slopes on sandstone of the Dakota formation are present in the area. Shale has been stripped from these domes by erosion.

5. Site geology. (a) General. Geology in the vicinity of Heron Dam is relatively simple. As stated above the dam was constructed on the northeast flank of North El Vado Dome, an elliptical-shaped dome whose surface expression is about 2-1/2 miles across. Sedimentary rocks of the Mancos, Dakota and Morrison formations were uparched forming the dome. At the damsite the beds dip gently away from the dome at 5° to 10°. Most of the Mancos formation that once covered the dome has been

ROCK COLUMN
VICINITY OF HERON DAM
SOUTHERN PART OF CHAMA BASIN
NEW MEXICO

AGE	FORMATION AND MEMBER		THICKNESS (feet)	LITHOLOGY
QUAT.	Landslide, slopewash, residual soil, alluvium		0 to 100	Clay, sand, gravel and boulders.
UPPER CRETACEOUS	MANCOS	Upper Shale member	650	Shale, silty, sandy in part, limy with limy concretions, few marine fossils; and thin beds of sandstone, grey.
		Niobrara member	800	Shale, clayey, sandy in part, limy, fossiliferous, black.
		Carlile member	450	Shale, clayey, limy, with large limy concretions, black, and thin beds of limy sandstone.
		Greenhorn member	70	Limestone, dense, thin to med. bedded, grey, with shale, limy, black.
		Graneros member	115	Shale, limy, sandy in lower part, with thin bentonite seams near top and base, grey black; concretions near base.
	Dakota		250	Sandstone, siliceous to limy, silty, carbonaceous, massive, cross-bedded, brown to white and shale carbonaceous, black.
JURASSIC	Morrison		700	Sandstone, fine to medium grained, clayey and shale, sandy, grey, green, red.
	Todilto		5 to 100	Gypsum and limestone. Thickness varies in short distances, grey, white.

FIGURE 9



Structural Features of Chama Basin and Adjacent Regions. Reproduced from New Mexico Geological Society Guidebook of Rio Chama Country, 11th Field Conference, 1960.

FIGURE 10

removed by erosion, exposing a dip slope on the sandstone at the top of the Dakota formation. The Chama River and Willow Creek have eroded their canyons through the Dakota formation and into the upper part of the Morrison formation in vicinity of the dam on the north side of North El Vado Dome.

(b) Structure. Deformations associated with doming at North El Vado Dome are jointing, normal faulting and shear zones. Jointing is the principal feature caused by doming and is conspicuous only in the top of the Dakota formation. The canyons of both Chama River and Willow Creek are joint controlled. Two normal faults are located from 500 feet to 1/4 mile upstream from the dam as shown on the surface geology for the dam and dike on figure 11. One strikes east-west, its traces are 2 miles long, displacement varies along its strike from an estimated 2 to 50 feet down to the north in places and down to the south in others. This fault was investigated by core hole, DH-33 where it intersected the fault plane in shale beds and was tight. The other fault strikes north-south, its trace is 1.1 miles long and displacement is estimated at 75 feet down to the west. Other faults were located in the reservoir area, but they were not continuous through the dam abutments and were not expected to be a source of leakage. Several shear zones were exposed by excavation of the cutoff trench in the right abutment.

(c) Joints. Two types of joints, radial and concentric occur related to the doming action. The radial joints radiate out from the center of the dome as spokes in a wagon wheel. The concentric joints circle the center of the dome. Both the radial

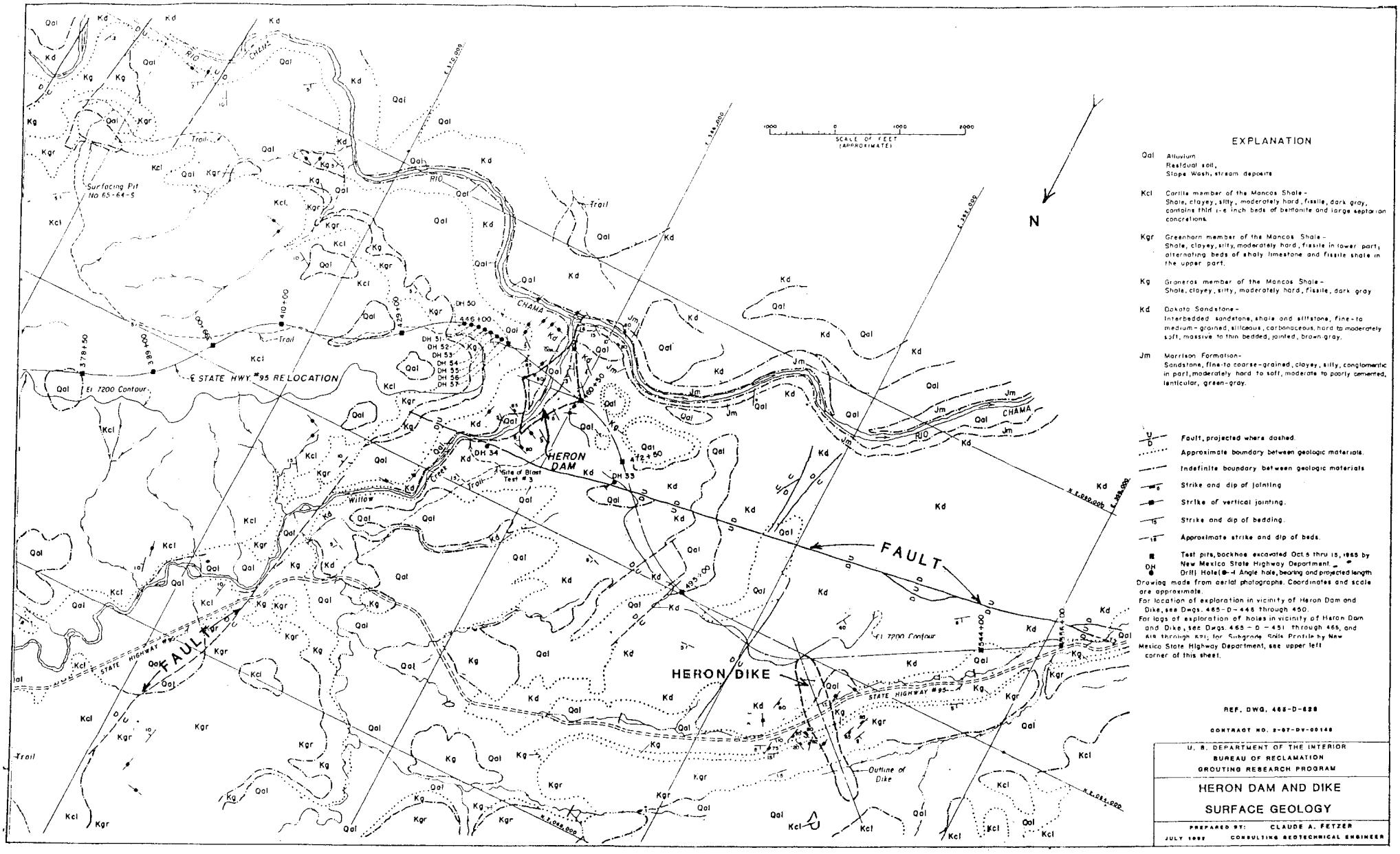

SCALE OF FEET (APPROXIMATE)
N
EXPLANATION
Qal Alluvium
Residual soil,
Slope Wash, stream deposits
Kcl Carlile member of the Mancos Shale -
Shale, clayey, silty, moderately hard, fissile, dark gray, contains thin 1-6 inch beds of bentonite and large septarian concretions.
Kgr Greenhorn member of the Mancos Shale -
Shale, clayey, silty, moderately hard, fissile in lower part, alternating beds of shaly limestone and fissile shale in the upper part.
Kg Graneros member of the Mancos Shale -
Shale, clayey, silty, moderately hard, fissile, dark gray
Kd Dakota Sandstone -
Interbedded sandstone, shale and siltstone, fine-to medium-grained, siliceous, carbonaceous, hard to moderately soft, massive to thin bedded, jointed, brown-gray.
Jm Morrison Formation -
Sandstone, fine-to coarse-grained, clayey, silty, conglomeratic in part, moderately hard to soft, moderate to poorly cemented, lenticular, green-gray.
Fault, projected where dashed.
Approximate boundary between geologic materials.
Indefinite boundary between geologic materials
Strike and dip of jointing
Strike of vertical jointing.
Strike and dip of bedding.
Approximate strike and dip of beds.
Test pits, backhoe excavated Oct. 6 thru 15, 1955 by New Mexico State Highway Department.
DH Drill Hole (●-4 Angle hole, bearing and projected length
Drawing made from aerial photographs. Coordinates and scale are approximate.
For location of exploration in vicinity of Heron Dam and Dike, see Dwgs. 465-D-445 through 450.
For logs of exploration of holes in vicinity of Heron Dam and Dike, see Dwgs. 465-D-451 through 465, and 616 through 621; for Subgrade Soils Profile by New Mexico State Highway Department, see upper left corner of this sheet.
REF. DWG. 465-D-628
CONTRACT NO. 2-07-DV-00148
U. S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
GROUTING RESEARCH PROGRAM
HERON DAM AND DIKE
SURFACE GEOLOGY
PREPARED BY: CLAUDE A. FETZER
JULY 1957 CONSULTING GEOTECHNICAL ENGINEER
HERON DAM
HERON DIKE
FAULT
FAULT
STATE HWY. #95 RELOCATION
STATE HIGHWAY #95
CHAMA RIO
Willow Creek
Trail
Surfacing Pit No 65-64-5
El 7200 Contour
Site of Blast Test #3
Outline of Dike
DH 50
DH 51
DH 52
DH 53
DH 54
DH 55
DH 56
DH 57
DH 34
DH 33
446+00
412+50
495+00
544+00
410+00
425+00
378+50
389+00
Y 1,119,000
Y 1,144,000
Y 1,169,000
X 2,050,000
X 2,055,000
X 2,060,000
X 2,065,000
X 2,070,000
X 2,075,000
X 2,080,000
X 2,085,000
X 2,090,000
X 2,095,000
X 2,100,000

FIGURE 11

and concentric joints are tension joints and are likely to be open at considerable depth in the more brittle sandstones but closed in less brittle or plastic rocks such as some of the shales. Many of the joints were slickensided, but seldom showed a detectable offset at bedding planes. The slickensides would indicate that some time during their stress history they were in compression accompanied with strike slip movement.

At Heron Dam the major joints strike north-south and are spaced a few inches to one foot apart and represent the radial joints. Joints representing the concentric set strike east-west and are spaced 50 to 100 feet apart. Results of water pressure tests and examination of rock cores revealed some of the joints to be open 1/8 to 1/4 inch in the sandstone, but tight in shale to the maximum depths of the exploratory drilling. Open joints were believed to exist below depths penetrated by the exploratory core borings.

The upper 20 to 50 feet of the Dakota sandstone forms a vertical cliff at the top of the canyon along Willow Creek on both abutments. Open stress relief joints occur in the sandstone which are open from a fraction of an inch to 2 or more feet for distances up to 150 feet on the surface. The joints are believed to be tight in the shale, but open and unhealed in the sandstone. The jointing in the Dakota sandstone is shown in figure 12.

6. Site investigations. Site investigations for Heron Dam were very extensive including surface mapping and subsurface drilling and sampling. The location of exploration and surface geology are shown on figures 13 through 16. Surface mapping of

P465-528-2611NA Heron Dam--San Juan-Chama Project--Colorado-New Mexico View of jointing in sandstone near the top of the Dakota formation exposed in the cut-off trench upstream from grout cap station 18+75. Most joints are tight, unhealed, steeply dipping to vertical and strike N 20° - 30° E. The joint on the man's right is open 1 to 2-inches in some places, in others it is filled with 1 to 2-inches of silt and clay.
Specifications No. DC-6558 Universal Constructors Inc.
7-21-70 **Bureau of Reclamation Photo by D. Manning**

Figure 12

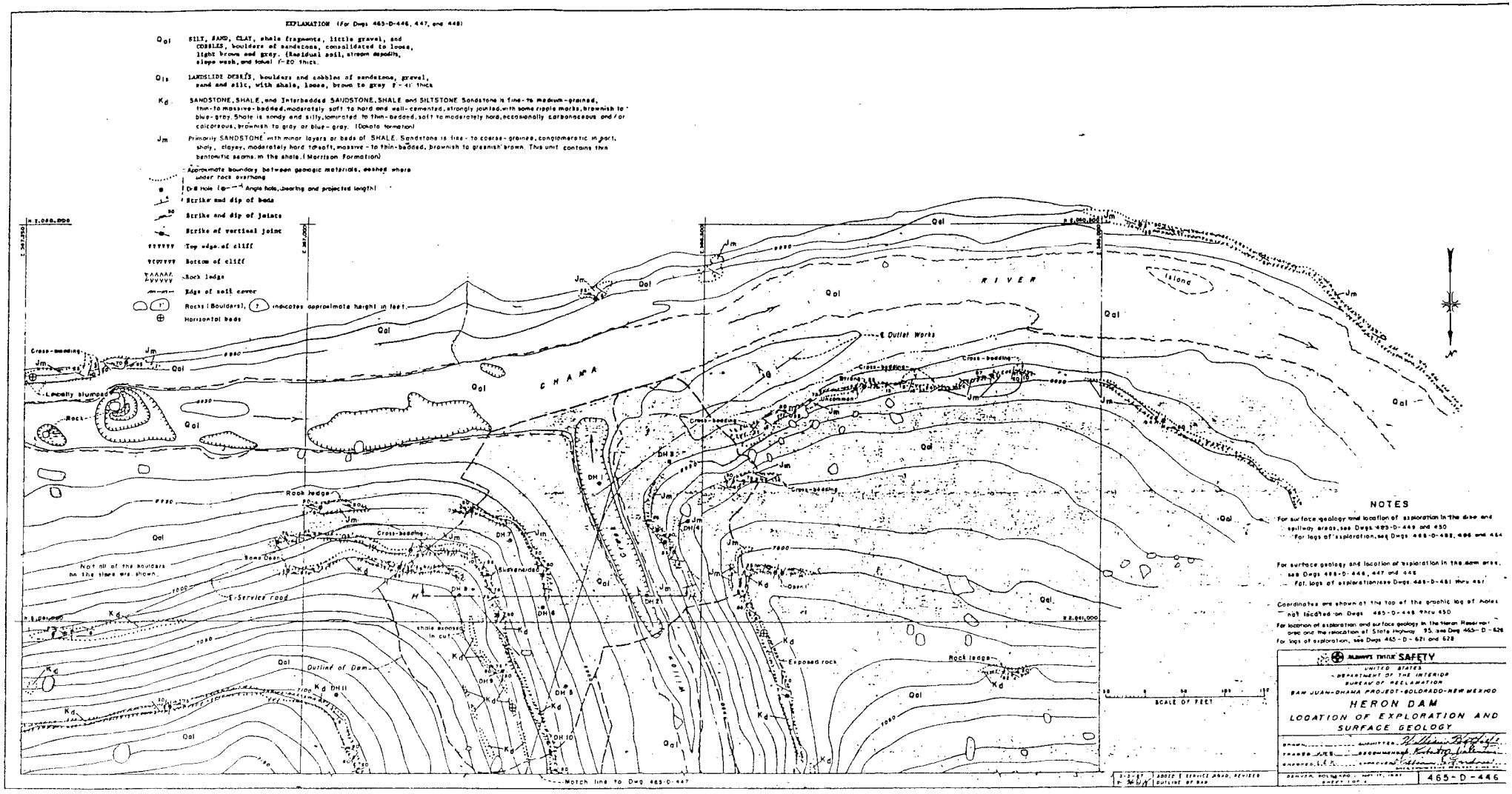

EXPLANATION (For Dwgs 465-D-446, 447, and 448)
Qal SILT, SAND, CLAY, shale fragments, little gravel, and COBBLES, boulders of sandstone, consolidated to loose, light brown and gray. (Residual soil, stream deposits, slope wash, and talus) (~20 thick.
Qls LANDSLIDE DEBRIS, boulders and cobbles of sandstone, gravel, sand and silt, with shale, loose, brown to gray (~41 thick
Kd SANDSTONE, SHALE, and Interbedded SANDSTONE, SHALE and SILTSTONE Sandstone is fine- to medium-grained, thin- to massive-bedded, moderately soft to hard and well-cemented, strongly jointed, with some ripple marks, brownish to blue-gray. Shale is sandy and silty, laminated to thin-bedded, soft to moderately hard, occasionally carbonaceous and/or calcareous, brownish to gray or blue-gray. (Dakota formation)
Jm Primarily SANDSTONE with minor layers or beds of SHALE. Sandstone is fine- to coarse-grained, conglomeratic in part, shaly, clayey, moderately hard to soft, massive - to thin-bedded, brownish to greenish brown. This unit contains thin bentonitic seams in the shale. (Morrison Formation)
Approximate boundary between geologic materials, dashes where under rock overhang
Drill hole (Angle hole, bearing and projected length)
Strike and dip of beds
Strike and dip of joints
Strike of vertical joint
Top edge of cliff
Bottom of cliff
Rock ledge
Edge of soil cover
Rocks (Boulders), (7) indicates approximate height in feet.
Horizontal beds
CHAMA
RIVER
Island
Outlet Works
Cross-bedding
Locally slumped
Rock
Rock ledge
Not all of the boulders on the slope are shown.
Service road
Slumped
Shale exposed in cut
Outline of Dam
Exposed rock
Match line to Dwg 465-D-447
NOTES
For surface geology and location of exploration in the dike and spillway areas, see Dwgs 465-D-449 and 450
For logs of exploration, see Dwgs 465-D-482, 483 and 484
For surface geology and location of exploration in the dam area, see Dwgs 465-D-446, 447 and 448
For logs of exploration, see Dwgs 465-D-481 thru 487
Coordinates are shown at the top of the graphic log of holes not located on Dwgs 465-D-449 thru 450
For location of exploration and surface geology in the Heron Reservoir area and the relocation of State Highway 95, see Dwg 465-D-628
For logs of exploration, see Dwgs 465-D-621 and 628
SCALE OF FEET
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN-CHAMA PROJECT-COLORADO-NEW MEXICO
HERON DAM
LOCATION OF EXPLORATION AND SURFACE GEOLOGY
465-D-446

FIGURE 13

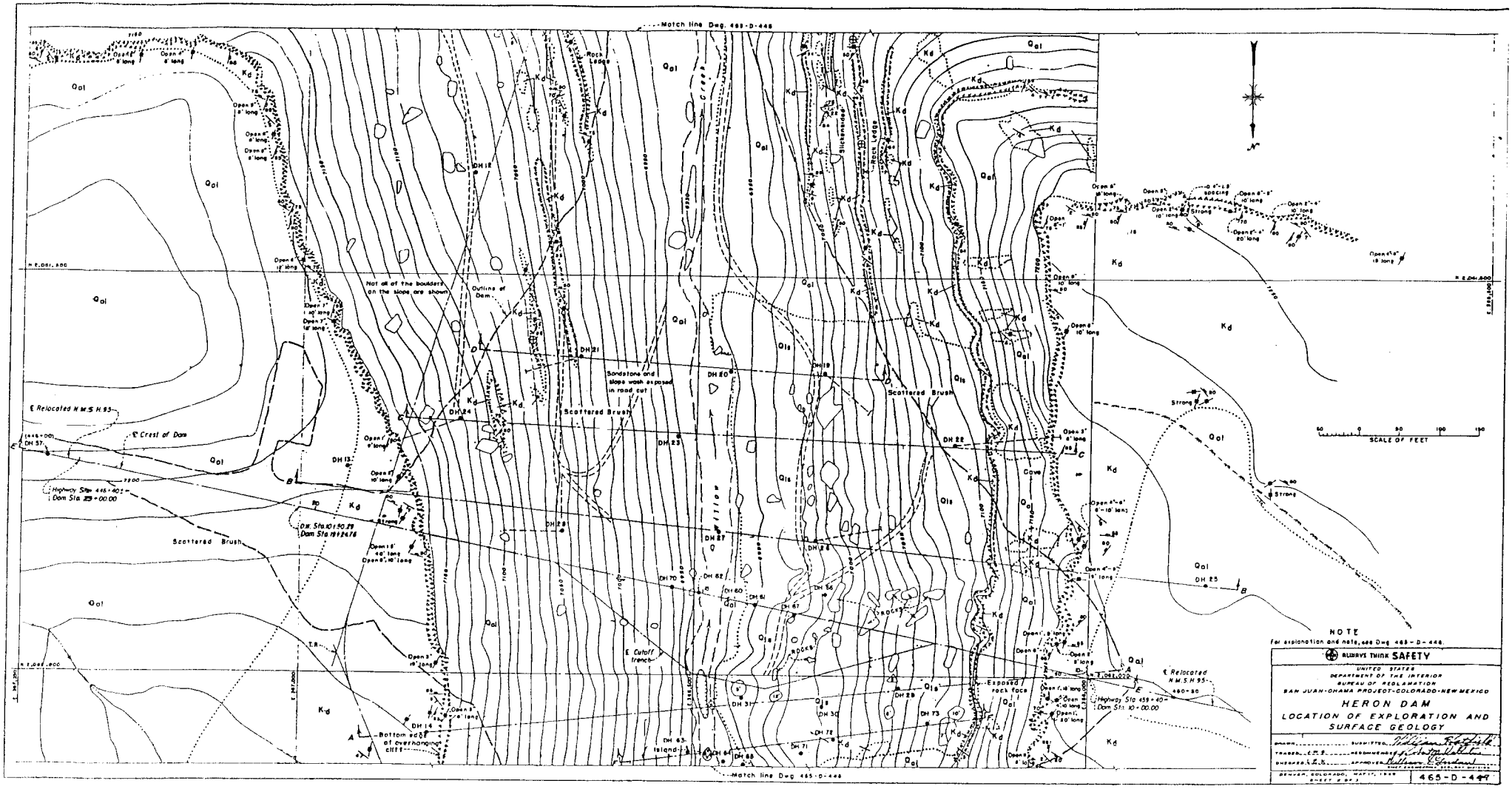
 Match line Dwg. 465-D-446
Qal
Kd
Qls
Rock Ledge
Slickensides
Creek
Willow
Not all of the boulders on the slope are shown
Outline of Dam
Sandstone and slope wash exposed in road cut
Scattered Brush
Crest of Dam
Relocated N.M.S.H. 95
Highway Sta. 445+40 = Dam Sta. 25+00.00
Dam Sta. 10+50.29 Dam Sta. 19+24.78
Cutoff trench
Exposed rock face
Cave
Rocks
Island
Bottom edge of overhanging cliff
Highway Sta. 459+40 = Dam Sta. 10+00.00
Strong
Open 8" 8' long
DH 12
DH 13
DH 14
DH 19
DH 20
DH 21
DH 22
DH 23
DH 24
DH 25
DH 26
DH 27
DH 28
DH 29
DH 30
DH 31
DH 37
DH 60
DH 61
DH 62
DH 63
DH 64
DH 65
DH 66
DH 67
DH 70
DH 71
DH 72
DH 73
A
B
C
D
E
F
N
SCALE OF FEET
50 0 50 100 150
NOTE
For explanation and note, see Dwg. 465-D-446.
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN-CHAMA PROJECT-COLORADO-NEW MEXICO
HERON DAM
LOCATION OF EXPLORATION AND SURFACE GEOLOGY
DRAWN
SUBMITTED
TRACED
RECOMMENDED
CHECKED
APPROVED
DENVER, COLORADO, MAY 17, 1962
SHEET 2 OF 3
465-D-447

FIGURE 14

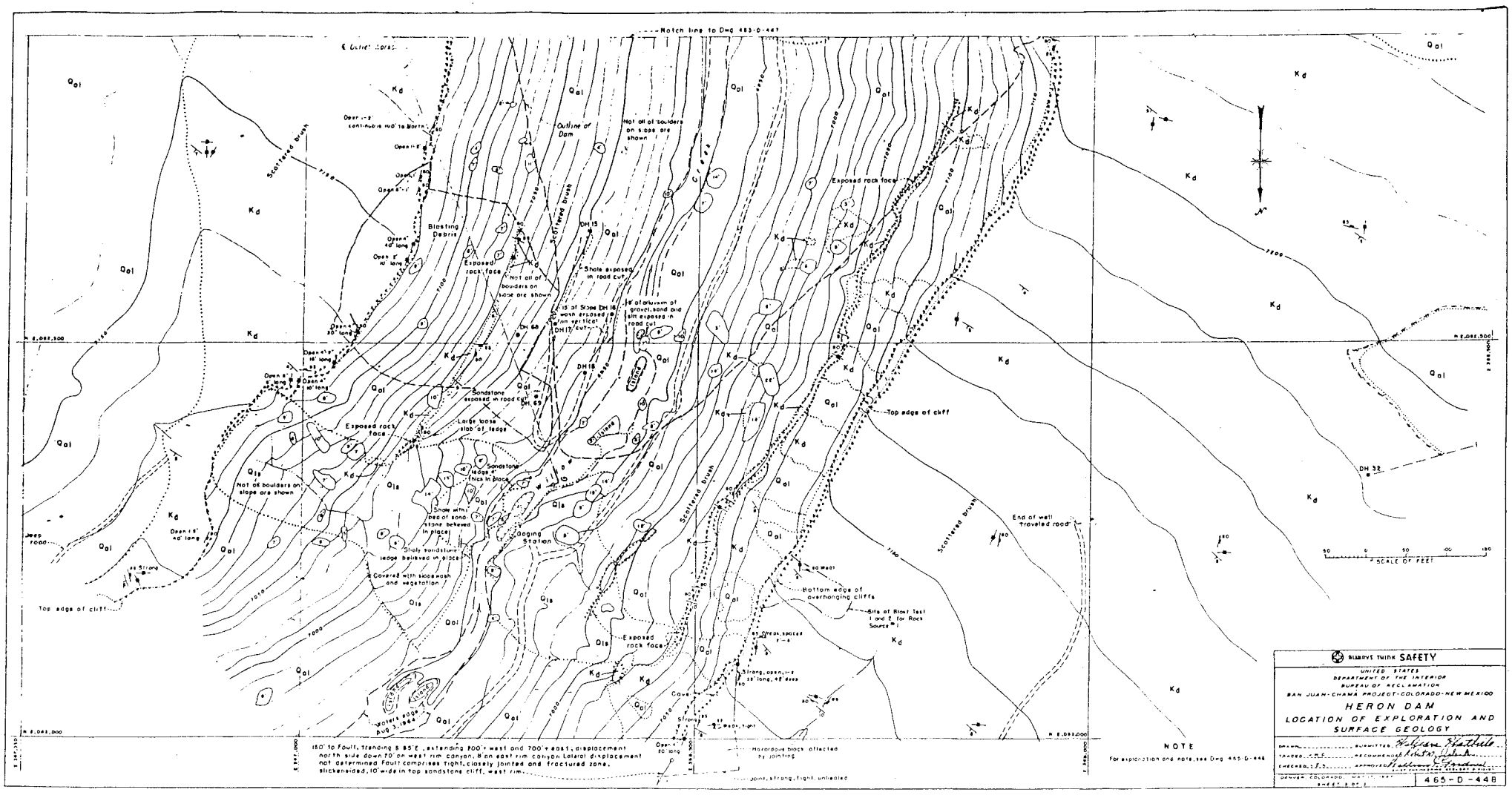

Notch line to Dwg 483-D-447
Outline of Dam
Not all of boulders on slope are shown
Exposed rock face
Blasting Debris
Shale exposed in road cut
Sandstone exposed in road cut
Large loose slab of ledge
Top edge of cliff
Not all boulders on slope are shown
Shale with lens of sandstone believed in place
Shaly sandstone ledge believed in place
Covered with slopewash and vegetation
Gaging Station
Scattered brush
End of well traveled road
Bottom edge of overhanging cliffs
Site of Blast Test 1 and 2 for Rock Source
Jeep road
SCALE OF FEET
150' to Fault, trending S 85°E, extending 700'+ west and 700'+ east, displacement north side down 70' on west rim canyon, 8' on east rim canyon. Lateral displacement not determined. Fault comprises tight, closely jointed and fractured zone, slickensided, 10' wide in top sandstone cliff, west rim.
Hazardous block affected by jointing
joints, strong, tight, unleaded
NOTE
For exploration and note, see Dwg 465-D-448
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN-CHAMA PROJECT-COLORADO-NEW MEXICO
HERON DAM
LOCATION OF EXPLORATION AND SURFACE GEOLOGY
465-D-448

FIGURE 15

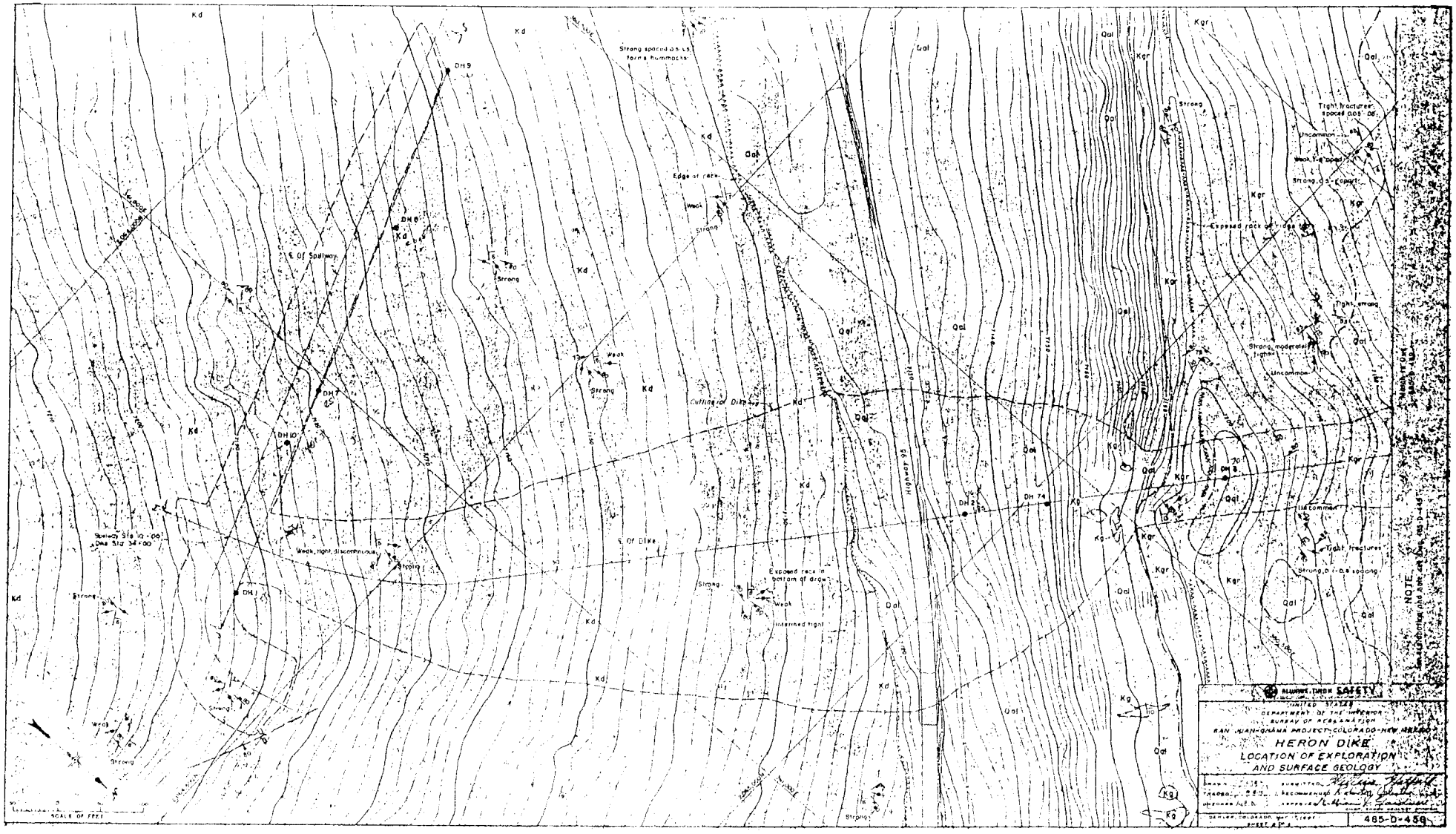

HERON DIKE
LOCATION OF EXPLORATION
AND SURFACE GEOLOGY
SAN JUAN-CHAMA PROJECT, COLORADO-NEW MEXICO
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
UNITED STATES
SAFETY
FIRST
NOTE
Kd
Qal
Kgr
Kg
DH 9
DH 8
DH 7
DH 10
DH 1
DH 2
DH 3
DH 74
℄ Of Spillway
Cutting of Dike
℄ Of Dike
Edge of rock
Exposed rock in bottom of draw
Strong spaced 0.5-1.5 forms hummocks
Tight fractures spaced 0.05'-0.5'
Uncommon
Weak, tight, discontinuous
Strong, moderately tight
Tight, strong
Tight fractures
Strong, 0.1-0.5' spacing
Spillway Sta 10+00
Dike Sta 34+00
SCALE OF FEET
485-D-459

FIGURE 16

the damsite and reservoir area was accomplished by Bureau geologists using topographic maps and aerial photographs. During construction, the foundation of the dam and abutments, the grout cap trench and the foundations of the dike and spillway were mapped on a scale of 1 inch equals 10 feet.

Exploratory drilling included 33 NX core holes totaling 3,455 feet for foundation investigations in vicinity of the dam; ten NX core holes totaling 579 feet for foundation investigations in vicinity of the dike and spillway; one 6-inch diameter core hole totaling 37 feet for investigations of sandstone for zone 3 material; and five NX core holes totaling 191 feet for investigation of a basalt lava flow for riprap. This drilling was done under contract with Sexton Brothers. This contract also included drilling shot holes and conducting three blast tests in the sandstone. Additional drilling by Bureau crews included eight NX core borings totaling 146 feet to determine depth of foundation rock east of the left abutment; twelve NX core borings totaling 266 feet to determine depth of foundation in the cutoff trench; two NX core borings totaling 132 feet for additional information in vicinity of the intake structure; and one NX core boring drilled to a depth of 31 feet for additional information at the dike.

A review of the exploratory borings revealed that the geologic information was recorded in detail in a professional manner.

Core recovery was excellent, averaging over 95% with not less than 90% recovery from any one hole.

Water tests were conducted by pressure or gravity in designated core holes as the hole was advanced. Eighteen of the first group of 33 core holes were water tested and nine of the second group of ten core holes were tested. However, of the core borings listed above only five or six were drilled close enough (within 150 feet) of the alignment of the grout curtain to be of any value in attempting to evaluate grouting conditions for design and estimating purposes prior to construction. In most cases they were too shallow to be used to relate water takes from percolation tests to predictions of grout take.

The locations of drill holes 60 through 74 are shown on figures 13 through 16 along the centerline of the dam and dike; however, the logs of these drill holes could not be found, and there is no reference to these holes in the geology reports. Hence, this study is based on the assumption that the holes were not drilled.

7. Ground water. Ground water is present in the vicinity of Heron Dam in the Mancos, Dakota and Morrison formations under perched and artesian conditions. It also occurs locally under normal conditions. However, a water table of regional extent is not present in the area.

Artesian conditions in the Morrison formation were indicated by grout holes drilled in the foundation area of the dam. Several grout holes penetrated water-bearing strata in the Morrison formation 25 to 100 feet below the surface in the foundation area. Water flows were estimated at 2 to 15 gallons per minute from these holes. Artesian conditions in the Dakota formation were

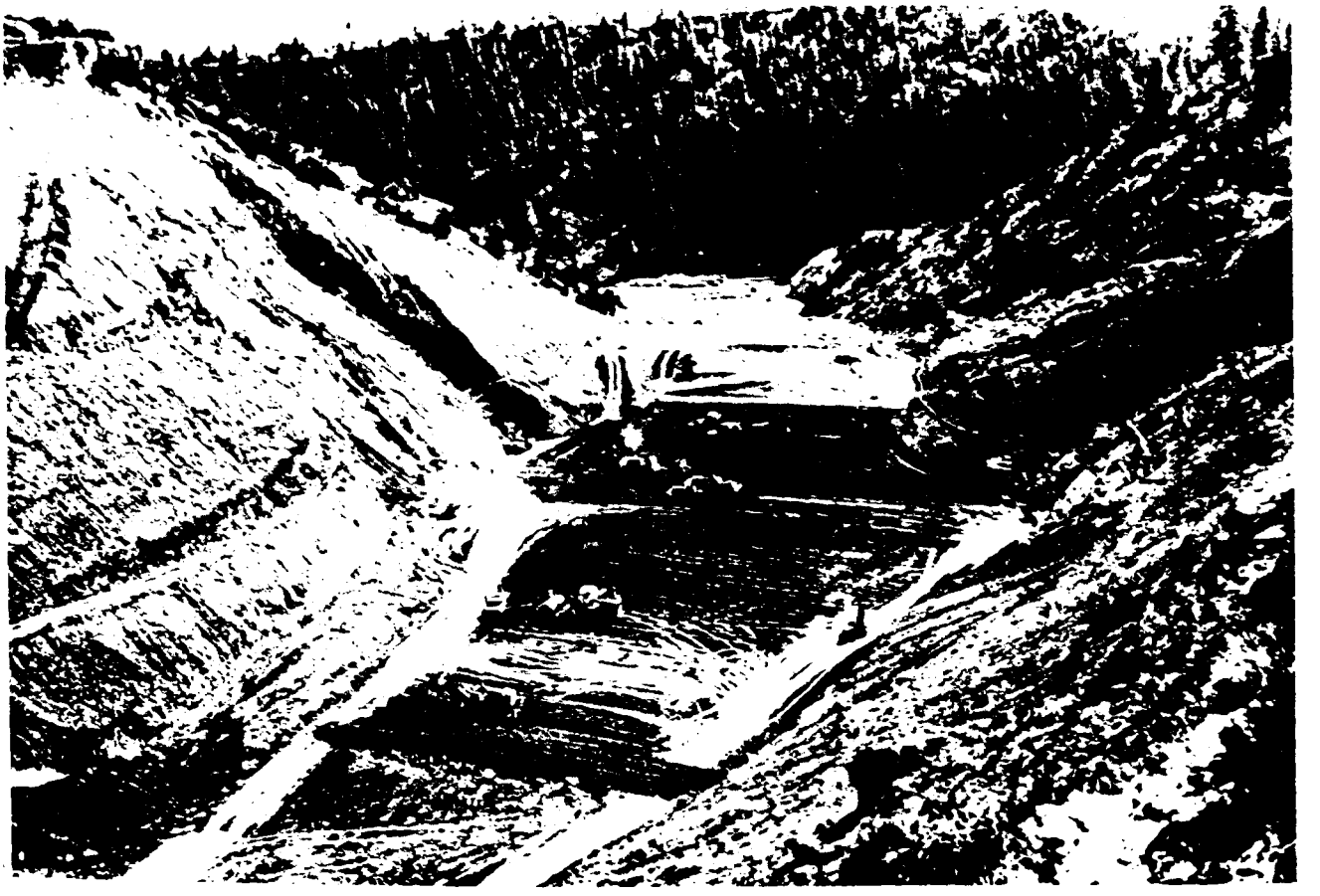
indicated by the water well drilled to supply the contractor's headquarters with water and for concrete operations. Water in this well was encountered in the Dakota formation between 238 and 240 feet below the surface and rose to within 100 feet of the surface. This well was drilled 1/4 mile northwest of the dam, with a collar elevation at 7,140 feet. Artesian conditions in the Mancos formation were indicated by water flowing from a uranium prospect hole drilled about 1-1/2 miles upstream from the dam on the east side of Willow Creek. Water with a strong odor of hydrogen sulfide flowed from this hole at an estimated 15 gallons per minute up to the time this hole was plugged. The driller reported water was encountered in this hole at a depth of 165 feet in the Mancos formation. Water under normal water table conditions occurred as seepage from sandstone of the Morrison formation exposed in the excavation of the outlet works stilling basin. This seepage occurred at and below stream level. Ground water under normal water table conditions is present in the alluvium along Willow Creek and Chama River, and is tributary to both. Perched water was indicated by seepage along bedding planes in the Dakota formation exposed in the cutoff trench excavation.

III. FOUNDATION TREATMENT

8. General. It is assumed that excavations for the abutments and foundations for Heron Dam, Dike, Spillway and outlet structures were made by drilling and blasting in the Dakota formation and perhaps the Morrison. Comments are made in several places in the Bureau's Final Construction Geology Report, stating that blasting caused bedding planes and joints to open, and caused overbreak of several feet because of the close spacing and orientation of the many joints in the geologic formations at the site. The contractor's blasting procedures were not available for review; but experience indicates that if uncontrolled blasting procedures are employed, problems of overbreak and opening of joints and bedding planes, and creation of new fractures can occur. It is not known how the blasting procedures changed as foundation grade was approached, i.e. whether or not less blasting energy was imparted to the foundation rock as excavation neared grade by use of lighter charges and more closely spaced holes to reduce the burden.

9. Dam. (a) Abutments. The abutments were scaled and cleaned to firm material. A cutoff trench 200 feet wide at the bottom was excavated into foundation rock in both abutments as shown on figure 17. True bedding dips of 3° to 5° NE were measured in the abutments. A grout cap trench approximately three feet wide and three to six feet deep was excavated at the bottom of the cutoff trench.

The contact between the Dakota and Morrison formation occurs at elevation 6,958 on the right abutment and at 6,948 feet



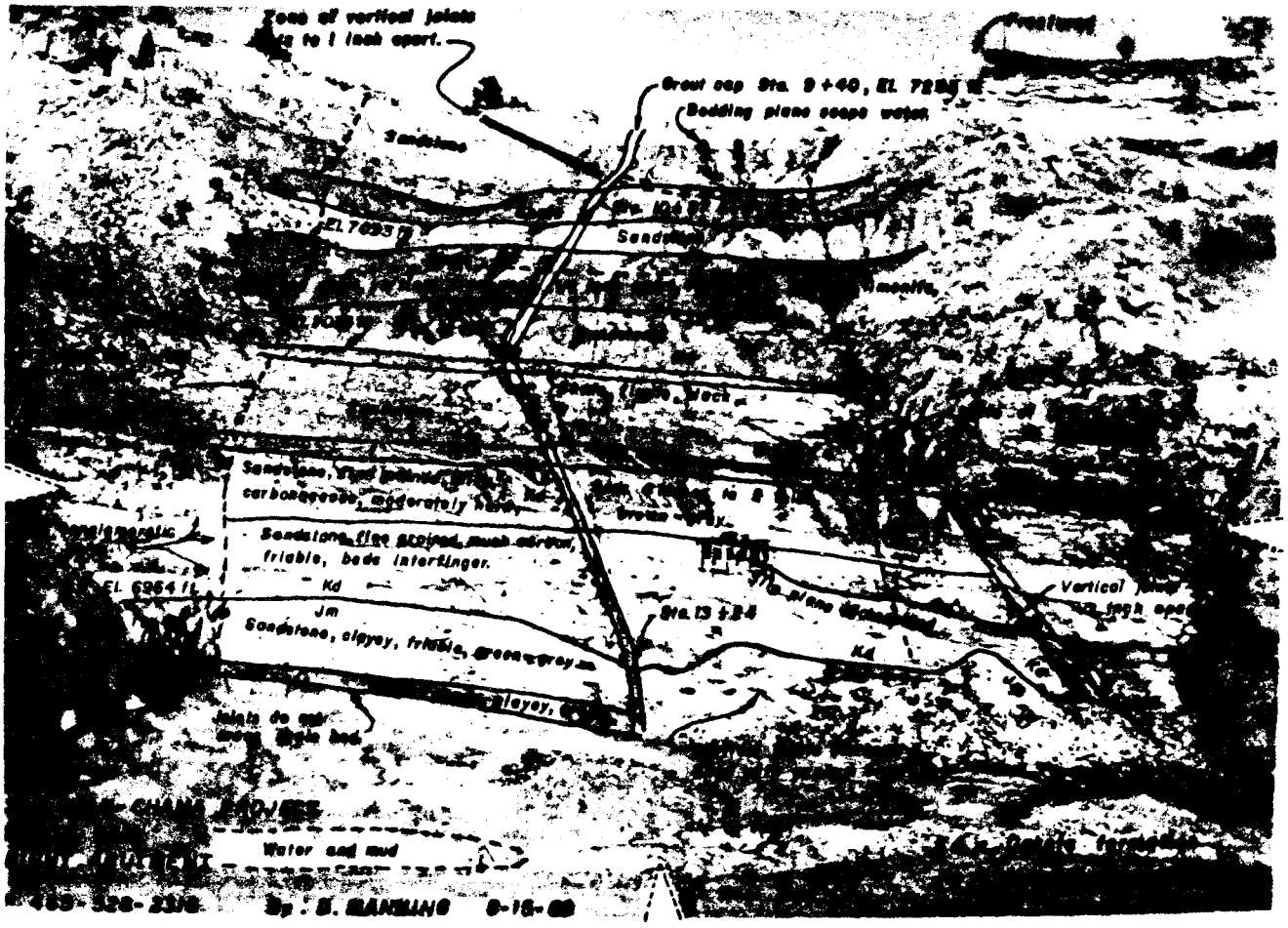
Looking downstream at embankment placing operations, Heron Dam.

P465-528-2437NA 10-14-69

Figure 17

in the left abutment. The contact is an uneven erosional surface as shown in lower part of figures 18, 19 and 20, but there is no apparent angular unconformity. The Dakota sandstone was fine to medium grained and locally conglomeritic, silty, carbonaceous poorly to well cemented, moderately hard to hard and jointed. Most of the exposed joints were tight, unhealed, dipped vertically, with strikes of N20°-30°E, E-W, N-S (the most open stress-relief set) and N50°W. A number of joints were open from 1/8 to 1 inch; others were filled with 1/8 to 6 inches of silt and clay. Gypsum crystals were observed on several joint surfaces. The shale beds were clayey, carbonaceous, silty, sandy, moderately hard, fissile to blocky and contained thin sandstone lenses. Beds in the Dakota ranged from a few inches to ten feet thick. Beds in the lower part of the Dakota interfingered. Several shear zones were exposed in the right abutment cutoff trench. They consisted of zones of closely spaced vertical joints and fractures striking east-west with minor displacements.

The Morrison sandstone was fine to medium grained, clayey, firm to moderately hard and poorly to moderately cemented. The shale beds were clayey and sandy, moderately hard and interfingered with sandstone. Most bedding planes were tight and moderately bonded. Most joints of the Morrison were tight, unhealed, hard vertical dips and strikes of N20°-30°E, N-S (stress relief set) and E-W. A few joints in sandstone were open 1/8 to 1/4 inch in places and were lined with gypsum crystals, others were filled with 1/4 inch to 1 inch of silt and clay. Joints of the N20°-30°E were most prominent and were spaced 2 to 12 inches

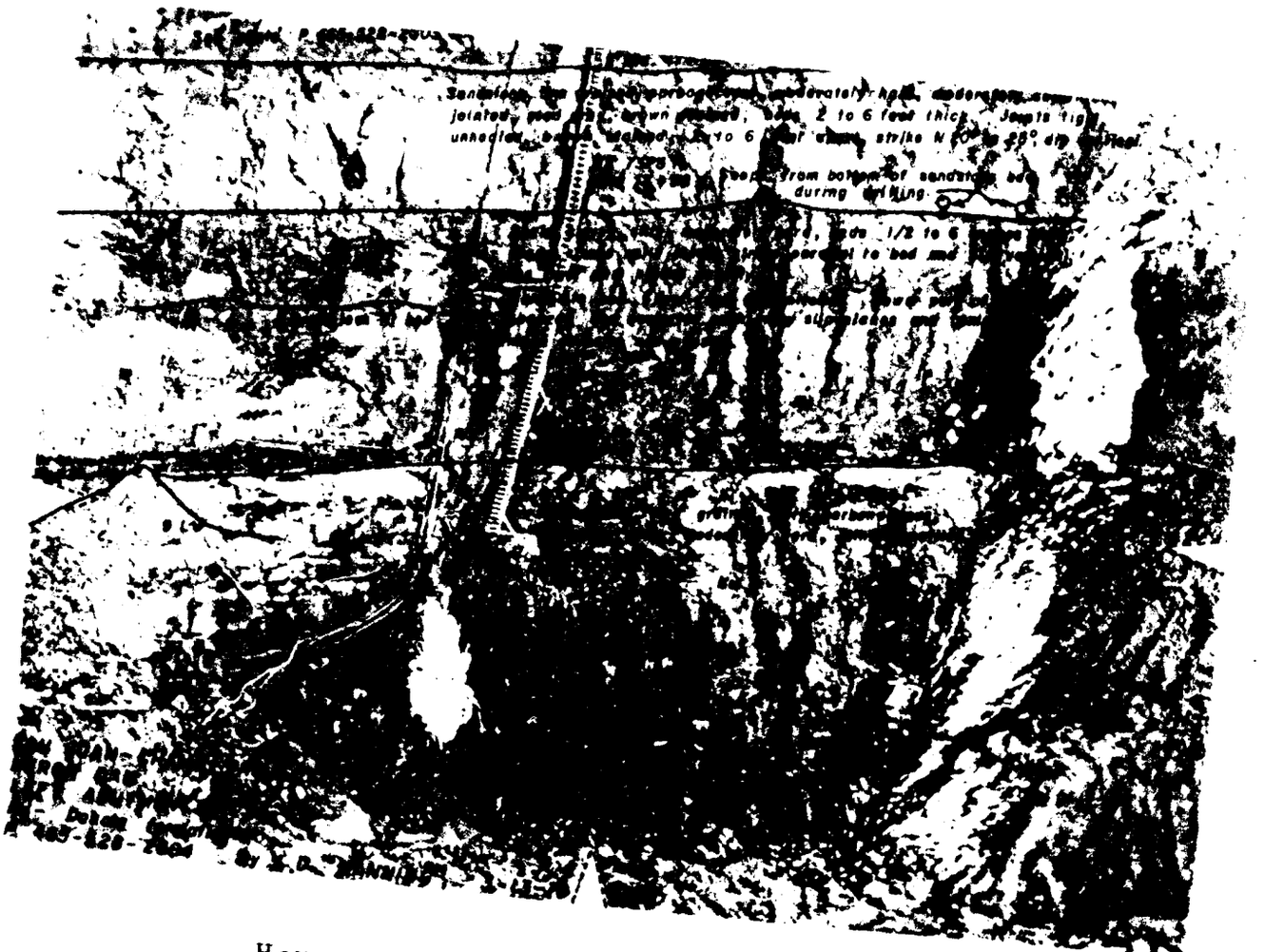


Heron Dam Right Abutment

Figure 18

Heron Dam Upper Left Abutment

Figure 19



Heron Dam Lower Left Abutment

Figure 20

apart. The vertical joints ended at the sandstone shale contacts. A review of the logs and notes on the geologic profiles indicates that the Morrison was easier to excavate and perhaps more shaley than the Dakota formation and hence tighter except for the joints.

(b) Valley bottom. The foundation in the valley bottom was entirely in the Morrison formation. The sandstone in the valley bottom was silty, clayey, poorly to moderately cemented, moderately hard and slightly friable. Beds were 1/2 to 2 feet thick. The beds dipped at an apparent dip angle of 2° NE across the entire foundation. Bedding planes were generally tight. The dip and strike of joint sets were described above, and were generally tight, indistinct and not healed. Water seeped and flowed from open joints and bedding planes exposed in the foundation excavation below water table. The clean up of the valley bottom is shown on figures 21 and 22, and filling of an open joint in the Morrison formation with bucket grout is shown on figure 23.

10. Dike. Sandstone of the Dakota formation and shale and limestone of the Mancos formation constitute the foundation of the dike. Three members of the Mancos formation were encountered, the Carlile shale, Greenhorn limestone and Graneros shale. The stratigraphy and lithology of these formations and their location in the dike foundation are clearly described in the Final Construction Geology Report and will not be repeated here. All these beds contained vertical joints spaced 2 to 12 inches apart and filled with clay, silt and gypsum. Where slope wash soil and weathered Mancos occurred along the dike alignment, a 30-foot

P465-523-2345NA Heron Dam and Relocation of State Highway No. 95--San Juan-Chama Project--Colorado-New Mexico Heron Dam embankment foundation following final cleanup and prior to placing Zone 1 material downstream of the grout cap and against the right abutment. The ladder on the slope is above the grout cap.
Specifications No. DC-6558 Universal Constructors, Inc.
9-8-69 Bureau of Reclamation Photo by D. Manning

Figure 21

P465-528-2338NA Heron Dam--San Juan-Chama Project--Colorado-New Mexico View of foundation of Heron Dam upstream from the grout cap near the toe of the right abutment. Sandstone of the Morrison formation is present in this area. Water in the lower left of the photo is seeping from a bedding plane.
Specifications No. DC-5558 Universal Constructors, Inc.
9-4-69 Bureau of Reclamation Photo by D. Manning

Figure 22

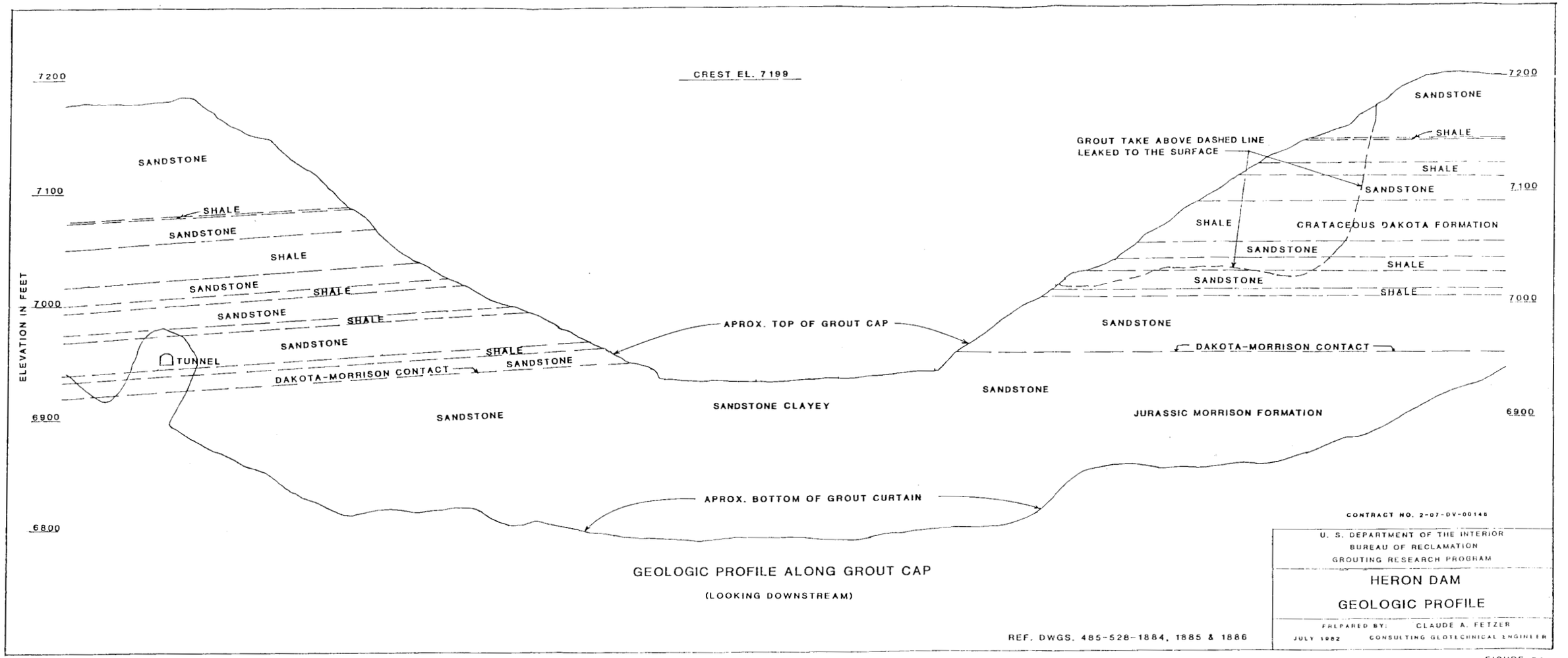
P465-528-2348NA Heron Dam--San Juan-Chama Project--Colorado-New Mexico View of partially open vertical joints in sandstone of the Morrison formation exposed in the foundation downstream from the grout cap. The joints strike N 25° E. Thick cement grout is being poured in these joints.
Specifications No. DC-6558 Universal Constructors, Inc.
9-10-69 Bureau of Reclamation Photo by D. Manning

Figure 23

bottom width cutoff trench was excavated from Station 10+00 to Station 25+05. Where sandstone of the Dakota was present, the surface was cleaned of vegetation and loose rock. A grout cap trench was excavated along the centerline of the dike between Stations 10+00 and 35+00.

11. Grout-cap trench. Excavation was accomplished by line drilling 3-inch diameter blast holes 6 inches apart on both sides of the grout cap trench. The blast holes were loaded with a length of primacord and detonated in an attempt to presplit the rock. Three-inch diameter holes were then drilled along the centerline of the grout cap, loaded with one to two sticks of dynamite and detonated with delayed electric blasting caps. The walls of the grout-cap trench were fractured in many places by blasting. Broken rock was excavated with a backhoe and by hand. After final cleanup, the geology exposed in the bottom and walls of the grout-cap trench excavated in the abutments and the foundation of the dam was mapped. The final geologic profile along the dam grout cap is shown on figure 24.

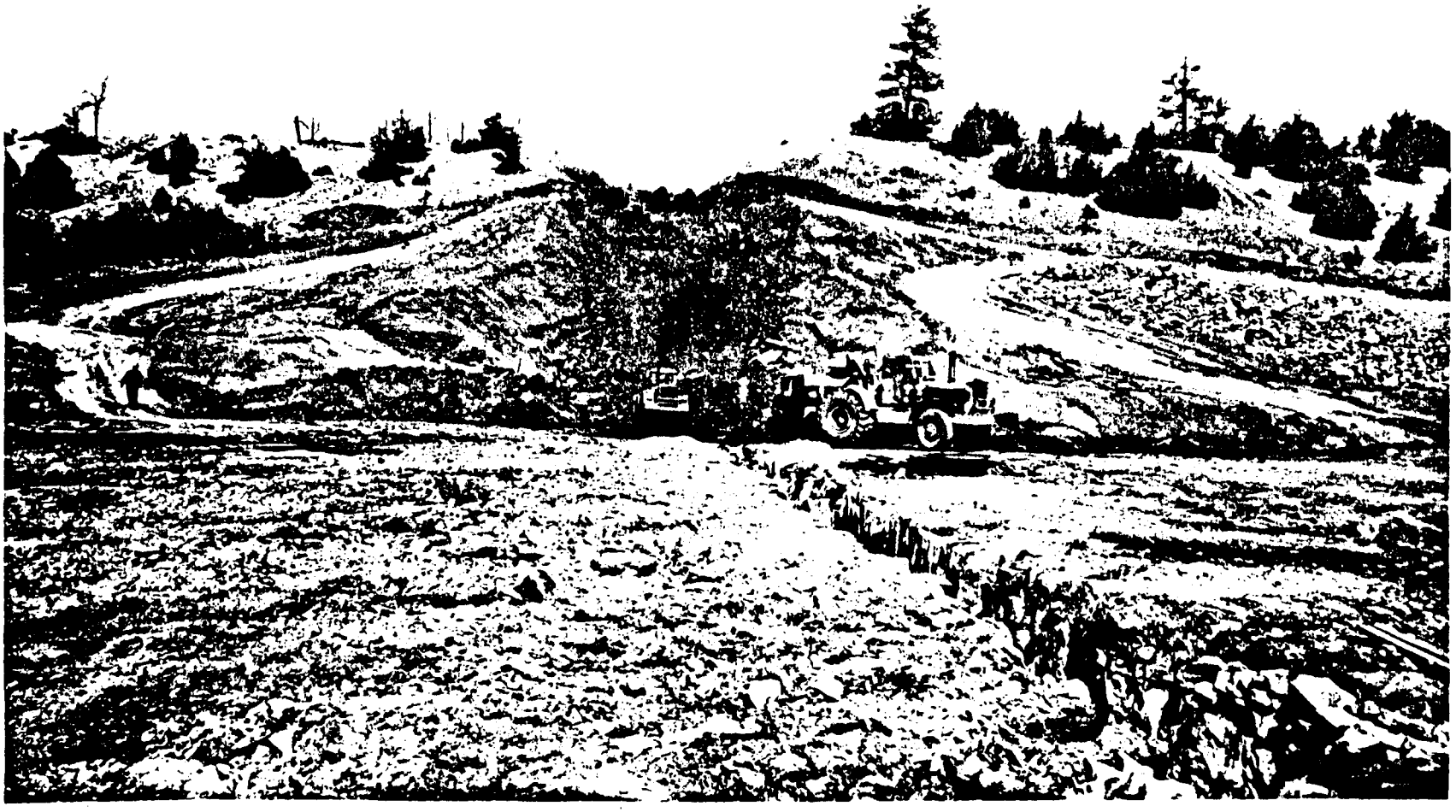
The grout-cap trench in the dike foundation was not mapped. The excavation for a portion of the grout cap in the dike foundation is shown on figure 26 and a section of completed grout cap is shown on figure 27. Sound rock was exposed in the bottom of the entire grout cap trench except between Stations 17+20 and 17+40 in the left abutment and between Stations 11+35 and 11+70 in the right abutment where weathered and fractured shale was exposed.



GEOLOGIC PROFILE ALONG GROUT CAP

(LOOKING DOWNSTREAM)

FIGURE 24



P465-528-1742NA Heron Dam and Relocation of State Highway No. 95--San Juan-Chama Project--Colorado-New Mexico Looking west at a section of the excavated grout cap trench on the dike. Foundation trench excavation is under way in the background between Stations 21+00 and Station 27+00.
Specifications No. DC-6558 Universal Constructors, Inc.
4-30-68 Bureau of Reclamation Photo by D. Manning

Figure 25

P465-528-1830NA Heron Dam--San Juan-Chama Project--Colorado-New Mexico View of the grout cap and foundation trench of the dike section looking southeast from station 11+60. Specifications No. DC-6558 Universal Constructors Inc.
7-2-68 Bureau of Reclamation Photo by K. Cooper

Figure 26

IV. GROUTING

12. Design of grout curtain. The pressure grouting program consisted of curtain grouting across the foundation of the dam and saddle dike with extension of the curtain in both abutments for 1,000 feet beyond the limits of the dam. The final report on foundation and outlet works grouting is reprinted in appendix A except for the drawings pertaining to the outlet works.

The plans and specifications provided a triple-line curtain for the dam between Station 9+50 at the top of the right abutment to Station 19+20 at the top of the left abutment. The primary grout curtain was to be constructed through a grout cap approximately 3 feet wide and extending into the foundation to depths ranging from 3 to 6 feet. Design of the curtain called for holes along the primary and supplemental curtains to be drilled to a depth of 260 feet with closure on holes to 10-foot centers. Holes on the extended curtains were in a single line on 30-foot centers to a depth of 260 feet. Heron Dike holes were drilled from a grout cap to maximum spacing of 10 feet and to angled depths ranging from 110 to 160 feet. A few blanket holes were drilled in selected areas to depths of from 5 to 40 feet to consolidate the rock prior to high pressure grouting. These holes were drilled through pipes embedded in the grout cap. Drilling and grouting was done by the ascending-stage grouting method with packers. Provisions were made for descending-stage grouting if required. All blanket holes were grouted by hooking directly to the grout pipe.

The primary curtain was constructed generally as per specifications; however, the third curtain 20 feet downstream from the

primary curtain was not constructed and the second curtain was stopped at elevation 7,095 on the left abutment and at elevation 7,150 on the right abutment.

13. Specifications. In addition to the curtain grouting previously mentioned, the specifications provided for pressure grouting the formation surrounding the outlet works intake structure, tunnel, gate chambers, adit and shaft; and it provided for pressure grouting any faults, shear zones, springs or other foundation defects.

The specifications were of a very general nature and left many items up to the direction of the contracting office. Such items included spacing of holes, grout pressures, water-cement ratios, etc. The specifications did establish a maximum depth of hole of 260 feet and a maximum pressure of grouting pressure of 250 psi. The minimum diameter of hole of that produced by an EX size bit, approximately 1-1/2 inches was required. The payment for cement by the cubic foot was based on the final pressure grouting quantity averages as follows:

Take in sacks per lineal foot of hole drilled	Payment
0.75 sack or less	Bid price plus 75% of bid price for the number of additional sacks required to average 0.75 sack of cement per lineal foot
0.75 to 1.25 sacks	Bid price
Greater than 1.25 sacks	Bid price up to 1.25 sacks but only 50% of bid price for all sacks of cement placed in excess of the 1.25 sack average

14. Water-pressure tests. The specifications required that "all holes shall be tested with clean water under continuous pressure up to the required grouting pressure in order to clean effectively the intersected foundation defects and to determine volume and extent of leakage." The results of pressure tests for holes that were hooked for grouting are not shown in the consolidated drilling and grouting records or the grout-line profile.

The grouting report in appendix A on page 10 states: "grouting of a stage was required if the water acceptance at the required pressure for grouting was greater than 2 cubic feet in 5 minutes. Initially a criteria of 1 cubic foot in 5 minutes was used, but experience showed that grout would be refused, so the water acceptance volume was increased."

The water testing operation was apparently not used as a means of determining the water-cement ratio to be used in the initial grout mix. This assumption is based on a directive to: All Grout Inspectors (which was unsigned and undated) in regard to water testing stated the following:

> "Water test all stages in which you set a packer. The primary reason is to see that your packer is holding. The secondary reason is to lubricate the hole. It is not absolutely necessary to water test the nipple before grouting."

15. Grout mixes. Grout mixes varied, depending on the type of treatment required. The water-cement ratios used in grouting were as follows:

Area of Grouting	Range of Water-Cement Ratios	Water-Cement Ratios Used Most Often
Heron Dam		
Blanket Grouting	5:1 to 1:1	2:1
Curtain Grouting	12:1 to 1:1	8:1
Heron Dike		
Blanket Grouting	8:1 to 1:1	1:1
Curtain Grouting	10:1 to 1:1	8:1
Curtain Extension - Right Abutment	8:1 to 1:1	8:1
Curtain Extension - Left Abutment	15:1 to 1:1	8:1

16. Grout-injection pressures. According to the grouting report in appendix A, the grout-injection pressures used at Heron Dam were as follows:

Blanket Holes - Main Dam - 10 psi at collar of hole

Foundation Curtain - Main Dam - 10 to 15 psi at the collar increased by 1 psi per foot of depth of the packer setting.

Curtain Holes Extension - Right Abutment - 10 psi at the collar with increases of 1 psi per foot of depth to the packer setting.

Curtain Holes Extension - Left Abutment - 10 psi at the collar with increases of 1 psi per foot of depth to packer setting with maximum 150 psi.

Blanket Holes - Heron Dike - not given

Curtain Holes - Heron Dike - 10 to 15 psi at the collar with increases of 1 psi per foot to packer setting.

17. Spacing of holes and closure. Grouting of the curtain holes was by the split-spacing closure method. The data on unit

takes of sacks per foot of drill hole for the primary and intermediate closure holes are presented in figure 2 of the grouting report in appendix A.

18. Refusal criteria. Grouting of a stage was terminated when the grout take in a zone was less than 1 cubic foot of grout mixture in the time and at the pressure shown below:

10 minutes at 50 psi or less

7-1/2 minutes between 50 and 100 psi

5 minutes at pressures greater than 100 psi

The above times represent a 50 percent reduction in the times listed in the specifications. Grouting was also terminated if less than two sacks of cement per hour were being injected for a period of 2 hours when pumping was continuous.

19. Final backfill of holes. The specifications required that all holes and all pipe remaining in place be filled with grout and that payment will be made at the bid price for pressure grouting foundations. The specifications did not indicate the method to be used in backfilling or whether or not the backfill is paid for as a connection. If required to use a tremie hose in the backfill operation (the usual and best method) some contractors consider this to be a separate operation and claim pay for a connection each time the hose is used.

V. ANALYSIS

20. Pre-construction geologic investigations. The pre-construction geologic investigations would have been more complete if drill holes 60 through 74 along the axis had been drilled to the planned depth of the grout curtain. The data available indicate that the drill holes did not extend to the depth of the grout curtain. The geologic conditions were well described in the geology report; but the geologic data were not related to design of the grout curtain, and only descriptive quantities were given for the grout takes.

21. Design of grout curtain. (a) Dike. The primary holes of the grout curtain for the dike were carried to depths ranging from 110 to 130 feet right of Station 25+00 (Station 25+00 to Station 10+79) and to depths ranging from 140 to 160 feet left of Station 25+00 (Station 25+00 to Station 34+67). The need to carry the grout curtain to these depths to the ends of the dike is questioned. DH-10 located along the spillway at the left end of the dike had a complete water loss from 130 to 138 feet (El. 7,091 to El. 7,085.5), but the primary holes at the end of the dike were taken down to elevations ranging from 7,070 to 7,050 feet. Even though water was lost in the drill hole down to the interval from 130 to 138 feet, the need to take the grout curtain to this depth at the end of the dike is questioned. The only serious seepage problem at end of the dike was in the rock disturbed by blasting for the spillway. Considerable blanket grouting was provided for the disturbed material, and no problems have developed to date; but the jumble of material left by the blasting could have resulted in piping of the backfill material for the spillway walls.

The depth of grout curtains for long low dikes is a difficult question for designers. In the instant case the dike at Station 25+00 has a height of about 94 feet, and it would appear logical to take the grout curtain at this point into the first shale layer or to a depth of about 100 feet. Between Stations 21+00 and 10+79, the dike has a maximum height of 40 feet. In this reach most of the grout takes were at very shallow depths except for the hole at Station 14+59 taking 435 sacks in a water loss zone from a depth of 53 to 54 feet. After the formations were tested, the deeper part of the holes could have been suspended, particularly where the head would have been extremely low. The ends of the dike are not located on narrow protruding ridges because of the flat topography; hence, the seepage path would be relatively long, which is another factor favorable to lesser depth for the grout curtain.

The holes were angled to the left 22 degrees from the vertical, thus intersecting the bedding at an angle of 73 degrees. Angling of the holes is considered to be appropriate as it gave the best chance to intersect vertical joints.

(b) Dam-abutment extensions. The purpose of the extensions was to provide a barrier in the vertical relief joints paralleling the Willow Creek channel. Seepage from the relief joints could have discharged immediately downstream in the right canyon wall of the Chama River. The curtain was drilled to an angled depth of 260 feet, which is to approximate elevation 6,960. The bottom of the curtain was only about 35 feet above the bottom of the nearby canyons. On the right extension, the bottom of the

curtain was only a few feet above the Dakota-Morrison contact, but was a greater height above the contact on the left extension. With the known geologic conditions, the length and depth used in the design of the grout curtain extensions are considered to be satisfactory.

(c) Dam. The grout curtain for the dam was designed to prevent seepage through the relief joints in the abutments and to prevent underseepage in the valley bottom. The abutment curtain tied into the extended curtain as previously described, and had adequate depth to intersect a zone of moderate water loss in a pressure test in DH-13 between elevations 6,974 and 6,918. The curtain in the valley bottom was carried down to an angled depth of 150 feet - a vertical depth of approximately 140 feet. The holes were drilled toward the abutments at an angle of 24 degrees from the vertical, and an overlap of 68 feet of the holes from the two abutments was made near the center of the valley. Grout takes were relatively small at depth in the Morrison formation of the valley bottom and the depths of the intermediate holes were appropriately reduced. Blanket grouting and filling of joints open to the surface with bucket grout were used in an attempt to seal the near surface bedrock openings. The extent of the cleanout and sealing of the narrow silt-filled joints is not known.

It is considered that the design of the grout curtain was satisfactory. In particular it is considered that the use of angle holes was most appropriate as this gave the best chance to intersect the vertical relief joints.

22. Specifications. A more detailed specification than that provided for the project would have been beneficial. The grouting could have been accomplished with much less difficulty had the contractor known in advance the specific type and capacity of grouting equipment required and the procedures that would be acceptable to the government. Specifications could probably be much improved by the changes and/or additions given below:

(1) Under grouting equipment specify the capacity of mixing tubs, agitator-sumps and minimum diameter of grout supply lines (from the sump to header and grout riser pipe) and the inside diameter of the packer. A grout plant having a minimum capacity of 50 to 60 gpm of grout injected at the specified gage pressure should be specified.

The minimum diameter of the pipe inside the packer should also be specified. This should be as near the inside diameter of the grout riser pipe as possible to eliminate restriction of flow and backpressure at the packer. The 3/8-inch pipe through the packer such as was used at Heron Dam would obviously impede the flow of grout and thus delay the operation.

The specifications should have required the pressure gages to be accurately-calibrated, high precision and in easily readable pressure subdivisions, i.e. 2 psi subdivisions for low-pressure grouting. Gages should be checked for accuracy at least once a shift.

(2) Under grouting materials require that a sufficient quantity of cement be stored at or near the site of work to insure that grouting operations will not be delayed due to a shortage of

cement. A minimum of 500 sacks should be on hand before beginning to grout any zone of any hole. (Depending on the number of grout plants.)

(3) The specifications should have indicated that the depth to water would be measured by government inspectors on completion of drilling and just prior to starting the grouting. The adjusted depth to water in a hole provides valuable information as to the depth of the lowermost cavity or open fractures in the hole. This is especially important where drillers' logs are poor and show little or no information as to the water loss and depth of cavities, clay seams, etc.

(4) The specifications should have required the use of a secondary grout placement unit (agitator and pump) at an elevation approximately that of the collar elevation, if the elevation difference between the primary grout plant and the grout header results in gravity pressure higher than the maximum allowable injection pressure.

(5) The method of sounding completed grout holes to determine if they are filled with solid grout should be specified. The method of backfill (tremie method) and provisions for payment (if allowed as connection) should be specified. To "top out a hole" may require several tremie operations with thick grout.

(6) The range of water-cement ratios expected to be used should be included in the specifications.

(7) The specifications required pressure washing by water and/or air but did not specify the extent or time required for washing.

(8) The specifications required pressure testing of grout holes prior to grouting but did not specify the amount of time required for testing, i.e. 5 minutes after maximum pressure has been reached, etc.

(9) Specification requirements for descending-stage grouting were "whenever required" as determined by the contracting officer. Although all grouting procedures are controlled by the contracting officer, it would probably be helpful to the contractor and the inspector to state the criteria when descending-stage grouting would be used, i.e. caving hole, total loss of drill water, major cavity, etc.

23. Grouting procedures. Ascending-stage grouting is generally well suited for use in weak, thin to medium-bedded sedimentary rocks as it permits the use of higher pressures in the deeper zones and minimizes the danger of the high pressures being applied to the rock in the upper levels of the foundation. However, the designers could not foresee the problems of setting packers in highly fractured and often oversized holes (due to drill-water erosion of the softer interbeds) and the large number of holes in which grout leaked to the surface. Descending-stage grouting could have been used beneficially at this project as the packer would have been set in a previously grouted section of the hole. The use of descending-stage grouting would have required considerably more drilling time than the method used. As the work was successfully accomplished by the ascending-stage grouting method, it must be concluded that the added time and cost for descending-stage grouting were not justified.

(a) Water-pressure tests. A common procedure is to grout any stage that takes 1 cubic foot of water in 5 minutes at the planned grouting pressure. The use of 2 cubic feet in 5 minutes on this project as the starting point for grouting was justified as grouting was refused at where the water test was 1 cubic foot in 5 minutes.

The results of the water pressure tests could have been used as a guide for selecting the initial water-cement ratio in accordance with the following tabulation:

Water Take (cu.ft. per minute)	Initial Water-Cement Ratio (by volume)
Up to 4	6:1
4 to 6	5:1
6 to 7	4:1
Over 7	3:1

(b) Grout mixes. A review of the grout mixes in the summary presented under section 15 above and in the summary of the daily reports indicates that very thin grout mixtures were used in the grout curtains. The reason for continued pumping with mixes in the range of 8:1 and 7:1 are presented as follows in a memorandum dated March 13, 1970 from Peter A. Aberle to Cecil Tackett, Subject, Letter dated February 24, 1970 from Universal Constructors "Claim for Additional Compensation for Grouting":

> "(2). Excessively high water cement ratios - On February 19, 1970, a hole at station 3+40 was being grouted. The take was at a constant rate of 12 sacks per hour using an 8:1 water-cement ratio by volume mix. The mix was changed to a 7:1 water-cement ratio mix and the pumping rate dropped to 10 sacks per hour. On February 20, 1970, a hole at station 10+38 was accepting grout at the rate of 16 sacks per hour using a 7:1 mix. The mix was

> changed to 6:1 and the grout take dropped to 12 sacks per hour. Numerous other similar situations can be cited. It is known fact that on as many occasions as cement takes decrease with a change in mix, cement takes also increase with a change in mix. However, this is not known until the change is made. I have the firm belief that every stage in every grout hole is important and must be grouted with a maximum effort and using the thinner mixes will accomplish this in a more satisfactory manner in this particular type of rock."

As a general rule the thin mixes may have been required, however, a review of the summary of daily grouting records indicates several cases where thicker mixes could have been used to save time and to install a more competent grout. In the hole at dam Station 11+41, the inspector noted that "the hole was on suction and had no back-pressure over 68 hours of pumping." The stage depth of 160 to 230 feet accepted a total of 1,026 sacks of cement injected at water-cement ratios of 6:1 or higher. In the same hole at stage depth 140 to 164 feet, a total of 1,200 sacks was injected over a period of 66 hours at water-cement ratios from 8:1 to 5:1.

The hole at dam Station 10+73 accepted 1,715 sacks at stage depth from 135 to 148 feet at water-cement ratios ranging from 8:1 to 5:1. According to the inspector's notes, "the hole was on vacuum throughout the pumping time." The hole was grouted over a period of 13 days but the grouting time is not given.

The results of pressure tests prior to grouting the two holes are not shown in the grouting records; however, for holes to accept grout on vacuum for a period of up to 68 hours, it can be assumed that water takes must have been quite high indicating that a relatively thick mix could have been used initially. Following

the initial injection, the grout should have been thickened to eliminate the vacuum.

Another problem contributing to the vacuum was the slow pumping rate of less than 2 cubic feet per minute of mixture possibly resulting from a small injection line and low pump capacity. This latter problem was addressed as follows in a letter dated April 17, 1970 from Project Construction Engineer to Chief Engineer, regarding the claim for additional compensation for grouting:

> "4. Maximum pumping rates.
> The maximum pressure being used is 150 psi and the minimum pressure is 15 psi which gives an average of 82.5 psi. A test was run to demonstrate to the subcontractor how the small 3/8-inch pipe through the packer restricted the flow of water at different pressures. For example, total volume was restricted to 11.2 cubic feet in 5 minutes with 88 psi. This equaled 16 sacks per hour with an 8:1 mix. This 3/8-inch pneumatic packer was used exclusively from June to October 1969. Subsequently a 3/4-inch packer has been used occasionally. Another test performed with a new pump indicated the grout pumps were too small. In a hole being grouted at the 90 to 115-foot stage, a 1/2-inch packer was used. The allowable pressure was 100 psi; however, only 75 psi could be attained. The maximum output of the pump was 34 sacks of cement per hour at a 5:1 water-cement ratio or 23.3 gallons per minute. The small packers and undersized pumps have precluded the subcontractor from pumping grout at high rates where such holes and stages would accept grout at the higher rates. This in turn has lowered the overall average rate of take."

The experience with the slow rate of injection at these holes even though a vacuum existed indicates the need to specify minimum sizes of injection pipes and minimum capacity of pumps; and in addition, it indicates that thicker grout mixes could have

probably been used. In this manner time would have been saved by the contractor and thereby reducing his basis for a claim. The daily record also indicated in the hole at Station 10+73 that the stage refused after 1,165 sacks and it was found that the packer was plugged. This also indicates that the pumping rate was too slow.

Placement of large quantities of thin grout mixtures as per these two holes may result in the grout travelling well beyond the limits of the planned or needed width of the grout curtain. There is no established rule to determine the width of a grout curtain. For an earth dam a grout curtain having width equal to the impervious core contact should be adequate. Where large takes occur it is considered advisable to drill exploratory holes to determine where the grout is going.

(c) Grout-injection pressures. It is not clear what the intended maximum pressures were. The specifications stated that the maximum pressure would be 250 psi, but did not state whether this was the collar pressure or the pressure at the packer. The specifications required the packer seal to be equal to the maximum grout pressure. If a pressure of 250 psi were used at the collar for a 260-foot deep hole with a packer set at 230 feet the required seal pressure would have been 218 (vertical depth) x 0.478 (8:1 grout) = 104 psi + 250 psi = 354 psi.

The contractor had difficulty in providing packer seals for collar pressures of 240 psi and the record in appendix A indicates that the maximum pressures were lowered from 240 psi to

200 psi in October, 1968 and subsequently lowered to 150 psi in February, 1969.

The need for a collar pressure of 250 psi at Heron is questioned. The water table at the dike was non-existent. The water table in the dam abutments was just above streambed, and the water table in the valley bottom had a slight artesian pressure. Hence the only pressure required to make the grout flow was the friction in the lines and the friction within the rock fractures except in the valley bottom to overcome the static water pressure. For the deeper holes where the rules shown in section 16 would have permitted a collar pressure of 220 psi for an angle depth of 230 feet for the packer, the pressure at the packer from the fluid in the line would have been 104 psi, and only sufficient additional pressures to keep the grouting flowing should be adequate to move the grout in the rock fractures a sufficient distance to form an adequate barrier width.

A review of the summary of daily grout records indicates that the pressures used exceeded the values established by the rules in section 16 above. For example:

Hole - Station 2+70 on 1,000' Extension Curtain-Right Abutment
Angle of hole = 24° Depth of Packer = 87 feet
Grout Pressure - Maximum 120 psi Minimum 97 psi

Vertical depth of packer = 79.5'

Pressure load of 8:1 grout at 79.5' = 38 psi

Maximum allowable = 10 + 79.5 = 89.5 or 90 psi

Hence the pressure used exceeded the allowable by 30 psi. There is evidence of excess travel of the grout from this hole

either by travel through existing fractures or by lifting of the rock from the following note in the record, "hole started to leak to hole at station 1+50 in process of drilling, so thickened mix to water-cement ratio 1:1."

Displacement of foundation rock up to 0.13 foot occurred in the grouting. Recurring displacement of rock was disclosed by vertical movement levels in the area between Stations 17+66 and 18+32 at distances of from 75 feet upstream from the grout cap to 80 feet downstream. (Drilling and Grouting Operations Report - L-10, April 27, 1970 to May 25, 1970.) Slight horizontal movement was also recorded. Photographs of the crack are shown on figures 28 and 29. A more complete description of the cracking in this reach is presented on page 31 of appendix A, and a photograph showing the rock bolts used to stabilize the rock block is shown on page 32 of appendix A.

Other indications of possible lifting that may be cited are as follows:

(1) Blanket hole at Station 18+82 - stage depth 3 to 14 feet. "Grout leaks after placing 576 and 890 sacks at pressures up to 10 p.s.i. Water leaks above 6" bentonite bed which crosses grout cap at station 17+73." This is an unusually large grout take for a blanket hole. Pressure of 10 psi at depth of 3 feet is excessive.

(2) Hole at Station 18+32, intermediate curtain. After placing 55 sacks - at stage depth 0-3 feet with pressure at 5 psi inspector noted "reopened joint across grout cap at station

P465-528-2567NA Heron Dam--San Juan-Chama Project--Colorado-New Mexico
View of joint 0 to 10 feet upstream of grout cap. Joint is normal to grout cap at station 18+38 and was opened while grouting the 20-40 foot stage in grout hole at station 18+20.
Specifications No. DC-6558 Layne Texas Company, Sub-contractor
4-28-70 Bureau of Reclamation Photo by D. Manning

Figure 27

P465-528-2569NA Heron Dam--San Juan-Chama Project--Colorado-New Mexico
View of joint 50 feet downstream of grout cap. Joint is normal to grout cap at station 18+38 and was opened while grouting the 20-40 foot stage in grout hole at station 18+20.
Specifications No. DC-6558 Layne Texas Company, Sub-contractor
4-28-70 Bureau of Reclamation Photo by D. Manning

Figure 28

18+38, 0 to 75 feet upstream of grout cap. Joint opened 1/16 inch at no time to our knowledge was pressure greater than 5 p.s.i."

(3) Hole at Station 10+73, stage depth 115 to 148 feet pressure 125 psi with 8:1 grout mix. Inspector's remarks "packer ruptured after 6 sacks had been injected. Hole was immediately washed. Grouting resumed after two hours. Hole refused at first but proceeded to take after 20 minutes."

The only reason that flow of grout would start after 20 minutes is that the pressure displaced the rock. Station 10+73 is located at mid-height on the right abutment. As the rock surface is sloping the effective vertical load of the rock at the packer would have to be computed accordingly. Furthermore, the shear strength along the intersected shale seam from El. 7,007 to El. 7,013 may have been less than the applied grout pressure. See geologic profile on figure 23 and grout profile on page 65 of appendix A.

It is concluded that grout pressures in some cases exceeded the pressures guide lines and that even the guidelines permitted pressures on the unsafe side because:

(1) The pressures were computed for the collar and not for the point of application.

(2) The allowable pressures were computed for the angle depth of hole and not the vertical depth.

(3) The topographic conditions of sloping rock surfaces of the abutments was not taken into account.

(4) The shear strength of a weak horizontal plane in the abutments was not considered.

(d) Spacing of holes and closure. Reference is made to figure 2 of appendix A. The progressive decrease in unit takes for all curtains from the primary spacing through each of the higher order of split holes to the terminal unit takes indicates that the rock had become tighter due to grouting. However, complete grout saturation may not have occurred along the main curtain of the dam as the unit take on the final-closure holes (10' centers) was 0.77 sack per foot and the unit take on the additional-closure holes (5' centers) was 0.57 sack per foot. These unit takes were appreciably greater than the unit takes for the final holes of the abutment extended curtains and of the dike curtain. Even though additional grouting was accomplished in the adjacent parallel curtain, it is considered from a closure standpoint that split-spacing to 2-1/2-foot centers should have been accomplished in areas of high takes until unit takes comparable to the other curtains were achieved.

A review of the available records does not indicate that exploratory core borings were drilled to check the effectiveness of the grouting. Drilling of such holes in areas of high grout take would have either verified that the main curtain was tight or that additional grouting was needed.

(e) Refusal criteria. The refusal criteria as changed in the program is considered to be adequate. On some projects a refusal criteria of 1 cubic foot of grout mixture in 5 minutes is used at any pumping pressure which is similar to the criteria of not grouting if the take in the water test is less than 1 cubic foot in 5 minutes at the planned grout injection pressure.

24. Unexpected geologic conditions. The main unexpected geologic condition encountered during grouting was the joint

pattern and weak horizontal seam on the left abutment that allowed movement of a large block of rock even though a low grouting pressure was being used at the collar.

25. Grout takes in relation to geology. An abstract from the Final Construction Geology Report is reprinted in appendix B and is titled "Grout Takes in Relation to Geology." This discussion was written by Kenneth R. Cooper, project geologist. The discussion is considered to be fairly complete and is considered to be an accurate evaluation of the subject matter. The drawings titled "Geology & Grout Curtain" are also included in appendix B.

Grout takes of up to 6,609 sacks in a single hole were probably unnecessary to obtain a seepage barrier of adequate width. When it was known that the grout was travelling as much as 600 feet upstream and downstream in the North-South relief joints the grout mix should have been thickened or buffer holes should have been drilled upstream and downstream to stop the excessive spread.

Where grout similar to brick mortar was found during clean up of the abutments, it must be assumed that the thicker grout mixes used in the blanket grouting picked up sand while travelling through the joints. This is not considered harmful to the seepage barrier. However there is concern that thin grout of 8:1 used elsewhere could erode holes in sandy joint filling that would make the filling more susceptible to piping than it was before grouting.

The descriptive quantities developed for the design in Volume III, Paragraph 133.4.2D, Foundation Data (Geology), were as

follows: (1) dam abutments, "small to moderate"; (2) dam channel section, "small to moderate"; and (3) dike, Dakota sandstone east of State Highway 95, "small to moderate".

Grout takes were as follows:

Right abutment 1,000-foot extended curtain	15,458 sacks
Right abutment dam - Sta. 0+00 to 13+43	36,343 sacks
Channel section dam - Sta. 13+43 to 15+27	3,936 sacks
Left abutment dam - Sta. 15+27 to 18+99	41,801 sacks
Left abutment, outlet works	
Access shaft radial holes	3,582 sacks
Tunnel radial holes	9,450 sacks
Left abutment 1,000-foot extended curtain	42,686 sacks
Dike - Sta. 26+00 to 34+67 excluding blanket grouting of blast-damaged area	3,417 sacks

It is considered that a take of 3,417 sacks along 867 feet of the dike would be small to moderate. The takes on the dam must be considered high takes whether measured by lineal foot of dam or lineal foot of drill holes, especially the takes per lineal foot of the main curtain and for the blanket holes. See figure No. 2, page 39 of appendix A. On the left abutment the takes from the tunnel and access shaft radial holes must also be considered to be part of the grout curtain. It is not possible to determine at this time how much of the dam grout quantity was due to flowing thin grout excessive distances.

26. Grout cap construction. It is an unusual blasting procedure to line drill rock on 6-inch centers and then load the line holes. The 3-inch holes are considered to be too large for the single string of prima-cord to be well coupled to the rock unless the prima-cord was carefully positioned and stemmed. Loading the line-drilled holes probably caused more blasting

damage than if they had not been loaded. The object of line drilling is to give the blasting holes a line of weakness to break to. Prima-cord detonated on 6-inch centers can impart excess energy into the rock causing severe overbreak. The concern is that excavation of the grout-cap trench will spring the beds and shatter the rock to the depth of the trench thereby creating a pervious zone adjacent to the grout cap.

27. Evaluation of grouting as related to seepage and pressures. (a) Seepage at dam. The inspection of September 11, 1980, found no seepage from the left toe drain of the dam and a small amount of seepage from the right toe drain with some flow also around the pipe. As the pipe is surrounded by gravel it should be expected that if there is flow in the pipe there will also be flow in the gravel around the pipe.

One wet area was found above the outlet works at the Dakota-Morrison contact. The area seeps and drips in quantities too small to measure.

This information indicates that the foundation is relatively tight, and that seepage problems to date are of no concern. The grout curtain undoubtedly blocked seepage that would have developed through the relief joints paralleling the canyon walls.

(b) Seepage at dike. The inspection of September 11, 1980, found that the toe drain was discharging only an insignificant amount of water. There were also seepage areas at the toe of the dike and some seepage was found emerging from the sandstone about 100 feet downstream from the end of the concrete spillway chute. The spillway under drains were dry, but there was a minor

amount of seepage on the invert of the drainage outlet channel a short distance below the drain outfalls. The maximum reservoir water surface before the inspection was El. 7,180.3 feet (July 17, 1980) and the reservoir water surface on the inspection date was El. 7,176.61 feet. If the water surface ever rises to the spillway crest (El. 7,186.1 feet), there could be seepage along side the spillway due to the open joints created by excavating the spillway.

(c) Seepage at Chama Canyon. Seepage from the Chama Canyon walls at locations up to 5 miles above the confluence of Willow Creek and the Chama River had been reported earlier than the September 11, 1980, inspection. At that inspection the closest spring was found about 1/2 mile from the confluence. Erosion in this area indicated that the spring had been in existence for some time. It was considered by the evaluation team that the quantity of seepage was probably only slightly influenced by Heron Reservoir.

This information indicates that the grout curtain extensions on both abutments were carried a sufficient distance and to a sufficient depth to prevent a short circuit through the abutments. It is not known if the seepage would have been any greater if the grouting extensions had not been constructed.

(d) Piezometric pressures - dam. It is reported that only the foundation piezometers have repeatable readings. A plot of the readings for May 6, 1981, are shown on figure 8. The scaled reading for the reservoir water surface for that day was El. 7,172 feet. As no tailwater was shown on the computer

printout, the net head is assumed to be from the rock foundation level El. 6,930 - a net head of 242 feet. Foundation piezometers are at two levels: Piezometers 8 and 9 are only slightly recessed below the rock surface; whereas, piezometers 1, 2, 3, 4, 5, 6 and 7 have their tips at El. 6,900, where they were placed in 4-1/2-inch-diameter drill holes from 25 to 30 feet below the rock surface. Piezometers 1, 2, and 8 are located upstream of the grout curtain and the remaining piezometers are located downstream of the grout curtain.

The following tabulation is presented for the foundation piezometers:

Tip No.	El. Ft.	Station (Dam)	Distance from grout curtain	Reading 5-6-81 (Scaled)	Head Ft.	Percent Net Head
1	6,900	14+00	155'U/S	6985	55	22.7
2	6,900	14+71	155'U/S	6968	38	15.7
3	6,900	14+50	125'D/S	7053	123	50.8
4	6,900	15+31	121'D/S	6971	41	16.9
5	6,900	15+25	277'D/S	6962	32	13.2
6	6,900	15+75	421'D/S	6947	17	7.0
7	6,900	16+25	574'D/S	6938	8	3.3
8	6,927.6	14+72	75'U/S	7044	114	47.1
9	6,923.1	14+72	25'D/S	6948	18	7.4

As shown in the plot and in the tabulation the highest piezometric level was recorded in piezometer 3 which is 125 feet downstream of the curtain. The next highest level was recorded in piezometer 8, which is 75 feet upstream of the curtain. Piezometer 8 has a 47.1 percent net head. Piezometer tips in rock represent point readings that may be heavily influenced by the joints intersected by the sensing zone; hence, large variations in the piezometric levels should be expected even for nearby piezometers.

The most obvious drop across the grout curtain occurs in the 96-foot drop in piezometer levels between the two near-surface piezometers (8 and 9). This reduction may be due to the grout cap more than to the grout curtain, or it may be due to the variations of water pressures in the fractures intersected.

The general trend of the deep piezometers is a gradual reduction in piezometric level from upstream to downstream with no particular drop at the grout curtain, which is what should be expected in the relatively tight rock found in the valley bottom.

It is concluded that there is insufficient data to prove or disprove whether the grout curtain has any effect on the piezometric levels in the foundation rock.

VI. RECOMMENDATIONS

28. Heron Dam and Dike.

(1) Check accuracy of dam foundation piezometers.

(2) Watch for seepage alongside spillway when reservoir level is at spillway crest level, and check for settlement of dike embankment overlying foundation area damaged by blasting.

29. Other earth dams.

(1) Extend exploratory drilling below planned depth of grout curtain or to known depths of "tight" formations such as shale.

(2) In designing depth of grout curtains for long low embankments, consider all factors including geologic conditions, hydraulic heads, topographic features, length of seepage path, etc. Be prepared to adjust depth during construction if no takes are found in the deeper stages of the curtain.

(3) Provide more detailed specifications on the minimum size of grouting tubes, capacity of grout plant and grout pumps. Where packers are to be used specify a minimum size hole equivalent to an AX size (1-7/8 inches) to permit use of a 3/4-inch grouting tube. Specify time for water-pressure tests.

(4) Use results of water-pressure tests as a guide in selecting initial grout mixes. Thicken grout if the rate of take increases and if the pressure decreases. Where vacuum conditions exist in a hole, increase pumping rate and thicken grout to develop a back pressure.

(5) Compute safe maximum pressures for different sections of the grout line and for the various packer settings

based on effective weight of the rock and the rock strength available to resist uplift and/or sliding. The safe pressures should be based on the point of application and not the collar as the effective weight of grout in the line to the packer must also bbe considered in computing the uplift and/or thrust. The specifications should clearly state that the maximum permissible pressures are at the point of application. The maximum permissible pressures at the collar would be less than at the packer.

(6) Where large quantities of thin grout are being injected in a hole, the condition should be evaluated by the geologist and engineer to determine if the spread of the grout is excessive and to determine if other procedures should be used to stop the spread. Exploratory holes should be used to determine the flow path of the grout and to determine if the grout curtain is tight.

(7) Where relief joints exist on abutments, consideration should be given to installing rock anchors before grouting starts; otherwise, the build up of hyrostatic pressure from freshly placed grout may be sufficient to displace a large block of rock even if minimal injection pressures are used.

APPENDIX

APPENDIX A

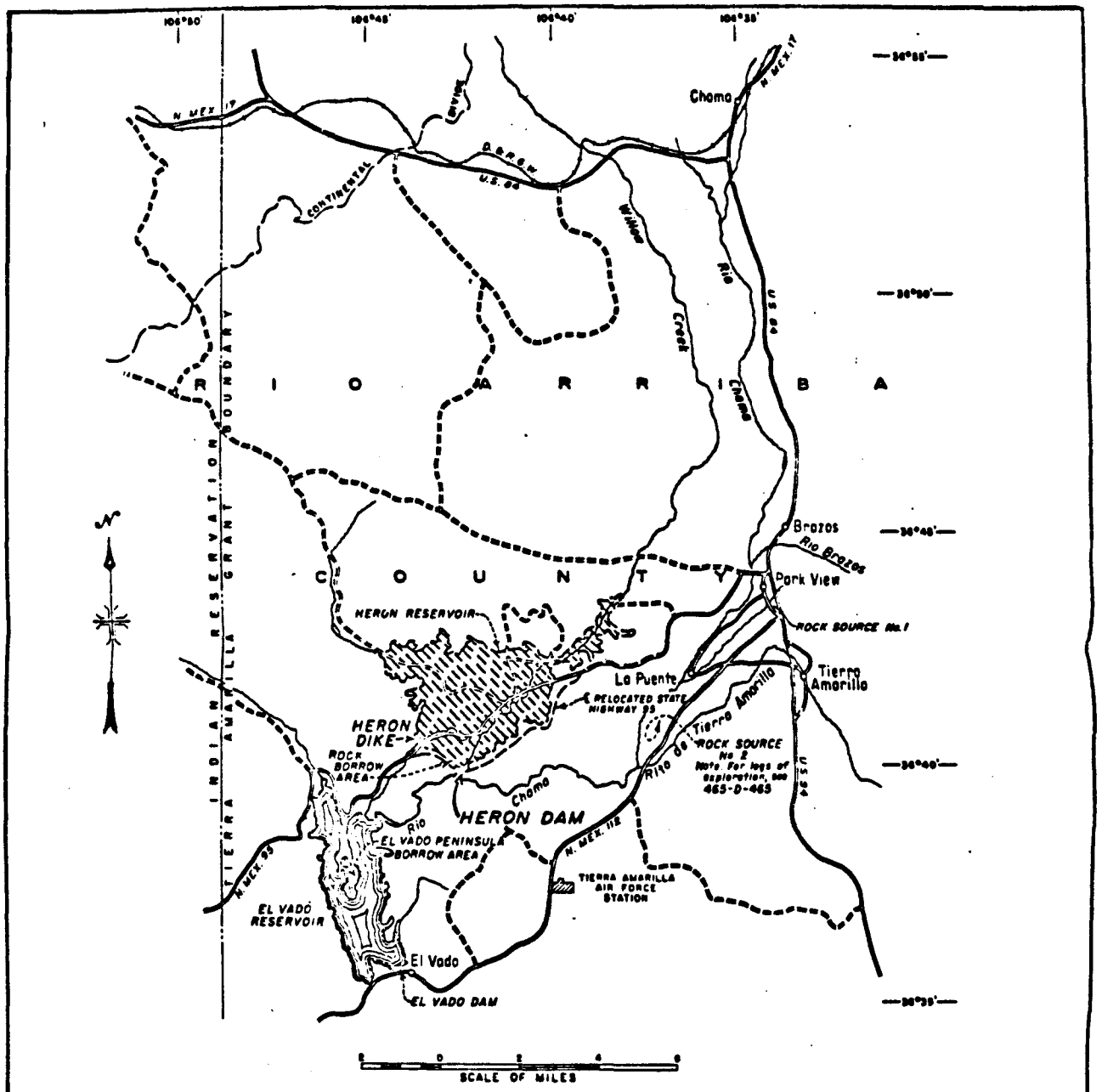
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

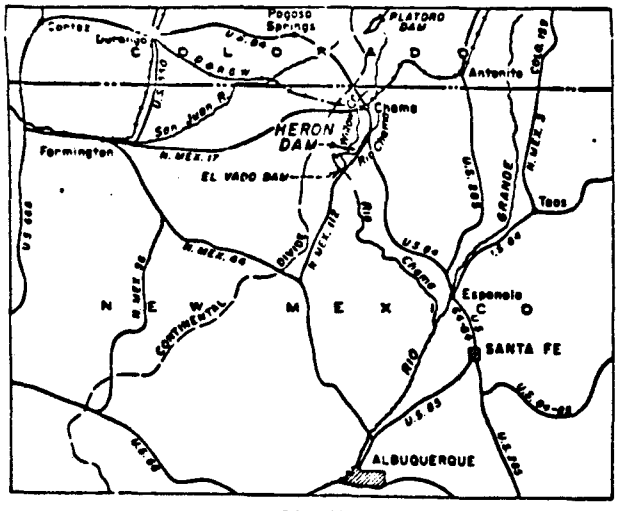
FINAL REPORT
ON
FOUNDATION AND OUTLET WORKS GROUTING
HERON DAM AND DIKE
SPECIFICATIONS NO. DC-6558

SAN JUAN-CHAMA PROJECT
COLORADO-NEW MEXICO

Constructed
1967-1971

JAN 1971





KEY MAP

8-3-67 B-RB	REVISED LOCATION OF ROCK SOURCE No. 1

ALWAYS THINK SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN-CHAMA PROJECT, COLORADO-NEW MEXICO

HERON DAM
LOCATION MAP

DRAWN L.E.P. SUBMITTED R. J. Larsen
TRACED R.L.P. RECOMMENDED H. G. Arthur
CHECKED RLW APPROVED A. A. Burman CHIEF ENGINEER

DENVER, COLORADO, MAY 31, 1966 — 465-D-468

FOUNDATION GROUTING, DRILLING, AND DRAINAGE

Introduction

Heron Dam, located in northern New Mexico, is an earthfill structure 275 feet high with a crest length of 1,220 feet. The dam was constructed across a canyon formed by Willow Creek, near its confluence with the Chama River. The foundation rock consists of Dakota sandstone interlaced with shale strata (Figure No. 3) in the abutments, with the Morrison formation outcropping in the foundation bottom.

Heron Dike is an earthfill structure, 94 feet high with a crest length of 2,405 feet and is located 1 mile northwest of Heron Dam. The foundation rock for Heron Dike consists of Dakota sandstone and the Graneros, Greenhorn, and Carlile members of the Mancos shale.

The foundation rock was drilled and pressure-grouted in the following areas:

(a) The foundation beneath Heron Dam and Dike embankments.

(b) Approximately 1,000 feet both to the left and to the right of the abutments of Heron Dam to make a continuous curtain with the dam curtain.

(c) The formation surrounding the outlet works intake structure, tunnel, gate chamber, adit to gate chamber, and access shaft.

Backfill grouting of the spaces between rock surfaces and the concrete lining of the tunnel and the shaft was performed by the same subcontractor.

Foundation drainage was provided for the outlet works tunnel downstream of the gate chamber by drilling EX (1½-inch) diameter holes on each side of the tunnel on 20-foot centers for a distance of 600 feet.

All of the drilling and grouting was performed by Keltner Drilling Company, Tulsa, Oklahoma, and Layne-Texas Company, Houston, Texas, a joint venture, subcontractors under Universal Constructors, Inc., of Albuquerque, New Mexico.

Drilling and grouting activities were begun April 1968 at Heron Dike and continued until August 31, 1970, with the completion of the 1,000 foot extended curtain on the right abutment of Heron Dam. Drawing Nos. 465-D-372, -374, -426, -427, -428, -429, and -430 show the general plan of the foundation grouting for Heron Dam and Dike.

Drilling and Grouting Equipment

Most of the drilling, including grout holes and drainage holes, was performed with Chicago Pneumatic No. 65 drills (Photograph No.

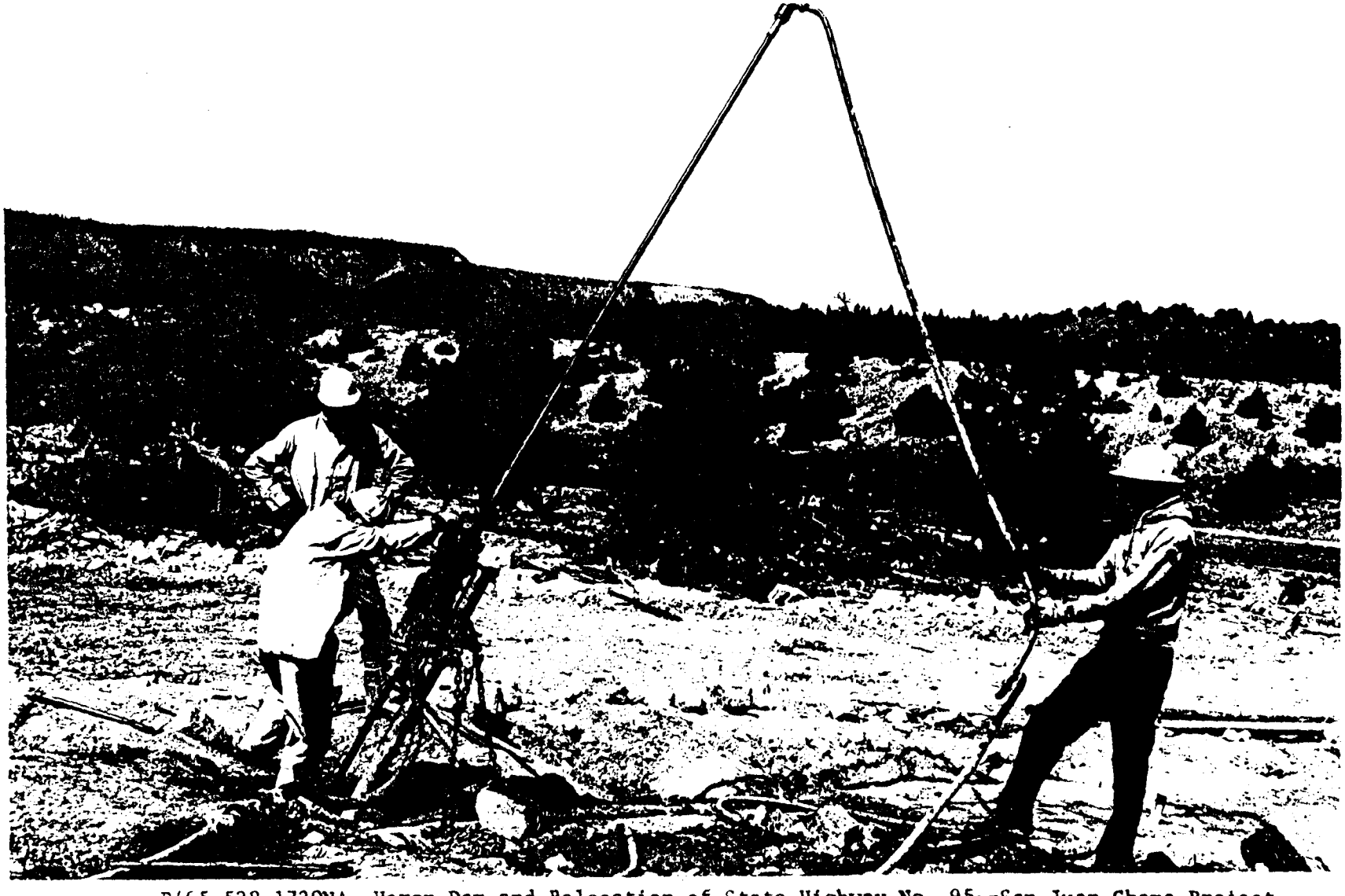
P465-528-1720NA). Some grout hole drilling in the foundation of Heron Dam and on both 1,000 foot extended curtains was performed with Reich Model C-350 drills (Photograph No. P465-528-2632NA). Portable grout plants were set up at various locations for different phases of the work. Initially the subcontractor used Moyno Model 3L6 grout pumps, exclusively. During October and November 1969, Golden Drilling Company from Golden, Colorado, performed some drilling and grouting for Keltner Drilling Company and Layne-Texas Company on the left abutment. Moyno Model 3L8 grout pumps were used by Golden Drilling Company and were found to be more efficient than the smaller Model 3L6. In March 1970, Layne-Texas Company purchased one Moyno Model 3L8 and one Moyno Model 3L10 grout pump. Before the completion of the job, these two pumps had pumped approximately 25,000 sacks of cement each, with only minor repairs and there seemed to be no significant loss in efficiency. The Model 3L6 grout pumps were used for pumping approximately 115,000 sacks of cement and required approximately 24 stator replacements during the job.

Three Moyno grout pumps and the Chicago Pneumatic No. 65 drills were powered by air motors. The compressed air was supplied by two or three portable and one stationary 600 c.f.m. air compressors. One grout plant was powered by a twelve-horsepower electric motor with air motor agitators and the remaining grout plant was operated by hydraulic motors. (Photograph Nos. P465-528-1719NA, -2226NA, and -2633NA).

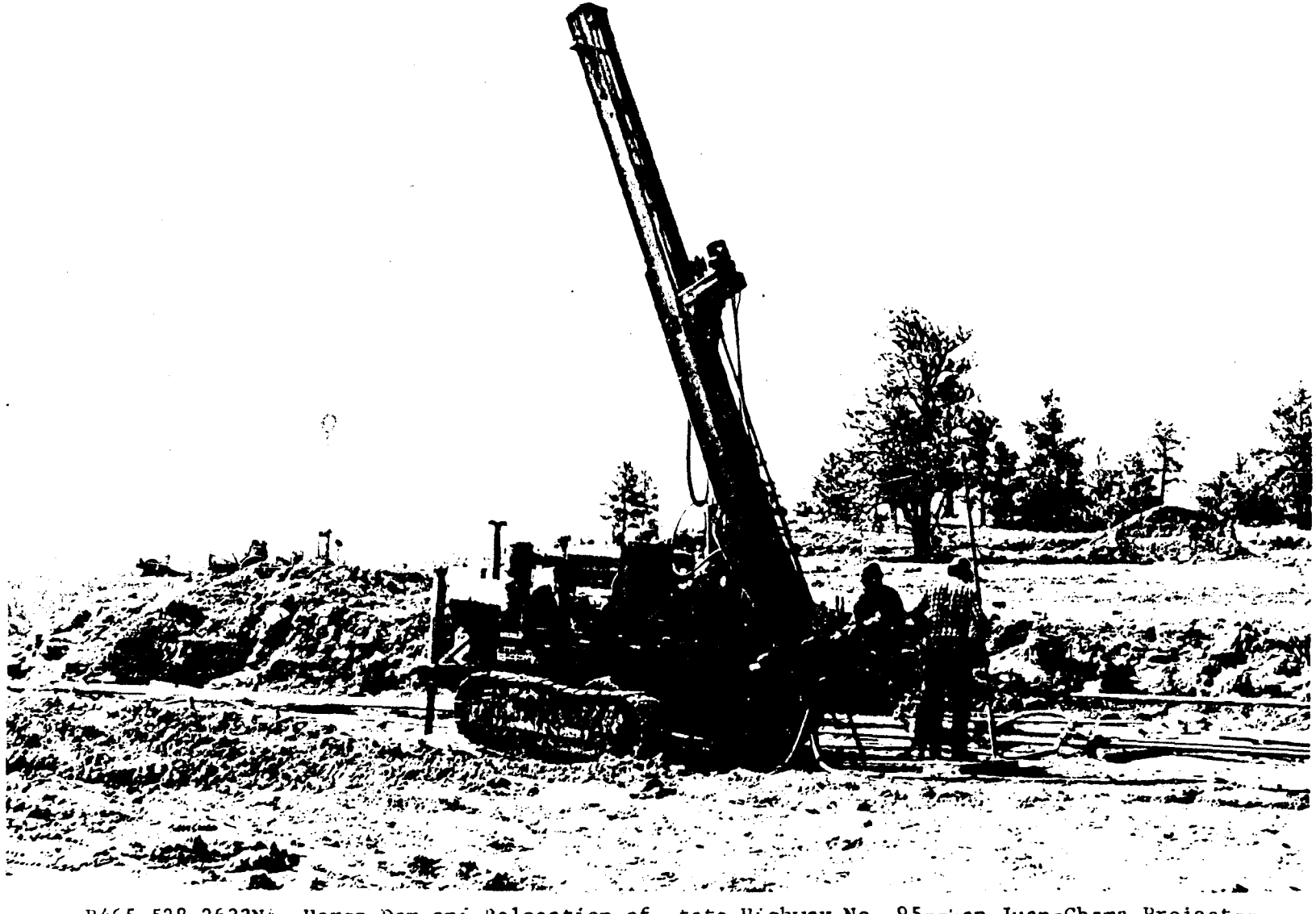
Grout plants consisted of a mixing tub and an agitator tub in series with the agitator tub supplying the pump. Tub capacities ranged from 13-cubic feet to 28-cubic feet. All plants were equipped with water meters. Grouting was performed through a pressure gauge equipped header (Photograph No. P465-528-1722NA) using 1½-inch diameter circulating lines and 3/4-inch diameter standard black iron grout pipe with pneumatic or leather-cup packers.

Following is a list of the major equipment used on grouting operations:

4 Chicago Pneumatic Model No. 65 Drills
2 Reich (Chicago Pneumatic) Model C-350 Track Drills
1 Jaeger 600 Air Compressor, Portable (Diesel)
1 Gardner-Denver 600 Air Compressor, Portable (Diesel)
1 Joy 600 Air Compressor, Stationary (Electric)
1 Gardner-Denver 6 x 4 x 6 Water Pump (Air)
1 Gaso 4½ x 6 Water Pump (Electric)
5 Grout plants double tub w/3 each Model 3L6, 1 each Model 3L8, and 1 each Model 3L10 Moyno Grout Pumps
1 2,000 Watt Light Plant (Kohler)
1 4,000 Watt Light Plant (Onan)
2 Dodge ½-ton Pickups
1 Chevrolet ½-ton Pickup
2 Dodge 4 x 4-3/4-ton Pickups
1 Chevrolet 1½-ton flatbed Truck
1 Ford - F1000 Model No. 477 Tractor w/30-foot trailer
1 Hobart 200 amp Welder (gasoline engine)



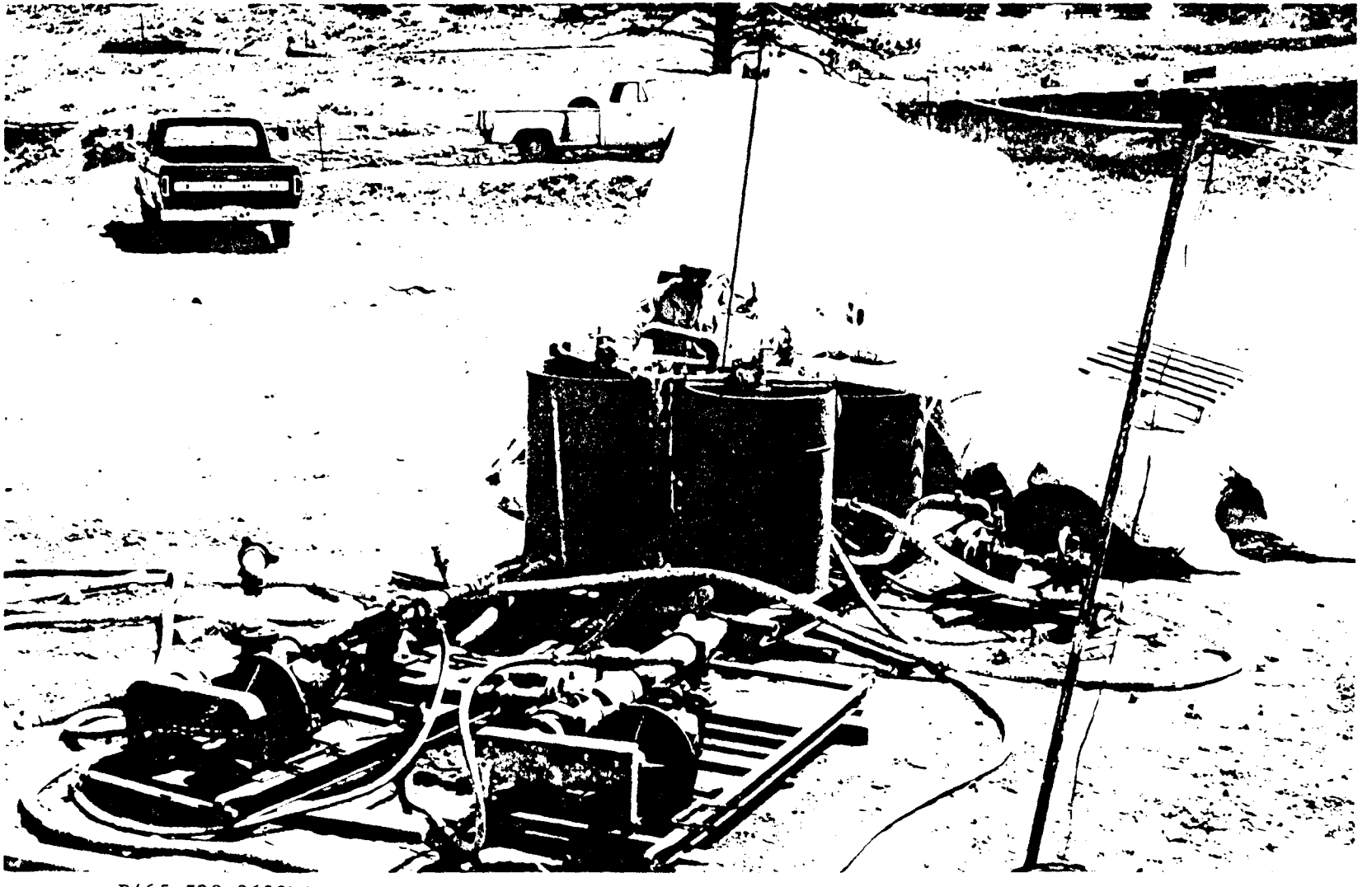
P465-528-1720NA Heron Dam and Relocation of State Highway No. 95--San Juan-Chama Project--Colorado-New Mexico Crew drilling the grout curtain hole on the dike foundation at Station 33+20. The hole is being drilled with a Model CP 65 rotary drill equipped with a diamond bit.
Specifications No. DC-6558 Keltner Drilling Company, Inc., subcontractor
4-17-68 Bureau of Reclamation Photo by D. Manning



P465-528-2632NA Heron Dam and Relocation of State Highway No. 95--San Juan-Chama Project--Colorado-New Mexico A Reich Track Drill, Model C-350, is drilling a hole at station 3+90 on the 1000 foot extended curtain in the right abutment of Heron Dam.
Specifications No. DC-6558 Universal Constructors, Inc., Layne Texas Company, subcontractor
8-13-70 Bureau of Reclamation Photo by D. Manning

P465-528-1719NA Heron Dam & Relocation State Highway No. 95--San Juan-Chama Project--Colorado-New Mexico View of grout plant manufactured by Damco Manufacturing Company, Dallas, Texas. Plant is powered by International Harvester engine which drives a hydraulic pump, mixer, tub, agitator tub and Moyno pump are driven by Hydraulic motors. Specifications No. DC-6558 Sub-contractors Keltners Drilling Company 4-17-68 Bureau of Reclamation Photo by D. Manning

P465-528-2226NA Heron Dam--San Juan-Chama Project--Colorado-New Mexico View of grout plant used at Heron Dam. Grout pump is a Model 3L6 Moyno powered by a 2-cylinder Wisconsin engine. A four speed pickup transmission is mounted between the engine and the pump for variable speeds. The Wisconsin engine was latter discarded and a 12 HP electric motor was installed.
Specifications No. DC-6558 Keltner Drilling Company, sub-contractor
4-24-69 Bureau of Reclamation Photo by D. Manning



P465-528-2633NA Heron Dam--San Juan-Chama Project--Colorado-New Mexico View of shop constructed grout plant used at Heron Dam. Plant has two agitator tubs and one mixing tub. Grout is mixed by the small centrifigal pump located to the right of plant. Grout pumps are Mayno Model 3L8 and 3L10 powered by HHM Ingersol Rand air motors 9½ h.p. capacity. Mayno pumps are manufactured by Robbins and Meyers, Inc., Springfield, Ohio. Specifications No. DC-6558 Layne Texas Company, sub-contractor
8-19-70 **Bureau of Reclamation Photo by D. Manning**

P465-528-1722NA Heron Dam and Relocation of State Highway No. 95--San Juan-Chama Project--Colorado-New Mexico View of the grout header apparatus used for pressure grouting the foundations of Heron Dam and Dike. The gage and valves are used to regulate the required pressure needed depending on the stage grouted.
Specifications No. DC-6558 Keltner Drilling Company, Inc., subcontractor
4-24-68 Bureau of Reclamation Photo by D. Manning

Grouting Criteria

Grout holes were drilled to their full prescribed depth before any grouting was done unless the drill water was lost during drilling. In this event the stage where the loss occurred was grouted and then drilling was resumed and continued until the required depth was reached.

Upon completion of the drilling of a hole, a packer was inserted and the hole was water-tested in stages, with each stage being grouted if needed. Stages were set at 30-foot increments below the 100-foot depth of the hole and at 20-foot increments above the 100-foot depth.

Grouting of a stage was required if the water acceptance at the required pressure for grouting was greater than 2 cubic feet in 5 minutes. Initially, a criteria of 1 cubic foot in 5 minutes was used, but experience showed that grout would be refused, so the water acceptance volume was increased.

Grouting was terminated when the grout take was less than 1 cubic foot of grout mixture in the times and at the pressures shown below:

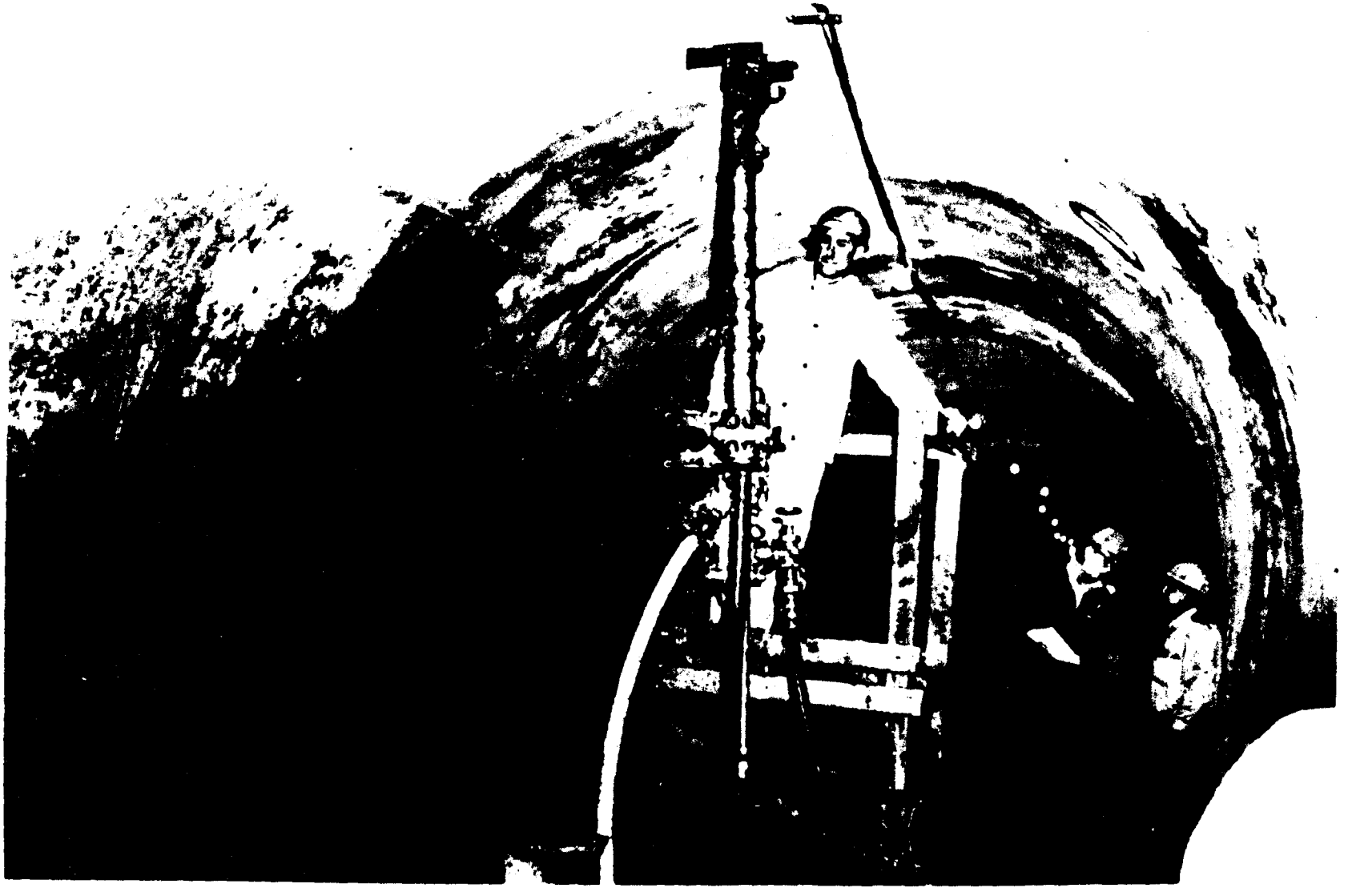
10 minutes at 50 psi or less
7½ minutes between 50 psi and 100 psi
5 minutes at pressures greater than 100 psi

Grouting was also terminated if less than 2 sacks of cement per hour were being injected for a period of two consecutive hours when pumping was continuous. These deviations from the specification requirements were allowed due to the thin grout mixes that were being used.

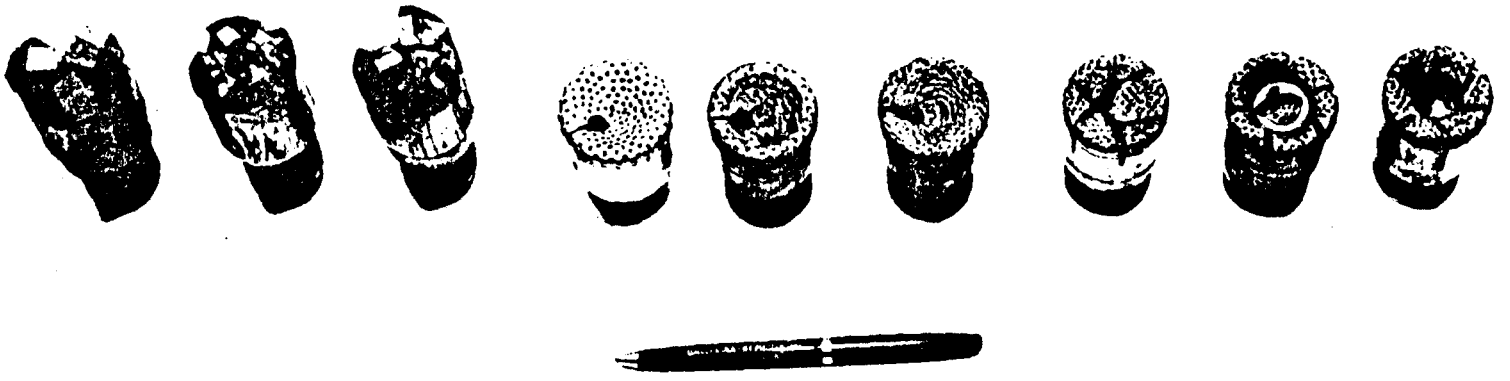
Drilling Methods

Drilling was accomplished with Chicago Pneumatic No. 65 drills mounted on a 4-inch diameter pipe and equipped with clamps designed to clamp onto a 2-inch or 3-inch diameter pipe nipple (Photograph No. P465-528-2214NA), and Reich (Chicago-Pneumatic) Model C-350 crawler mounted drills. The Reich drills were an all hydraulic drilling unit with a top drive rotary head. Diamond plug bits and drag bits were generally used for drilling the sandstone and shale members, respectively, (Photograph Nos. P465-528-1851NA, -1852NA, -2627NA, and -2628NA).

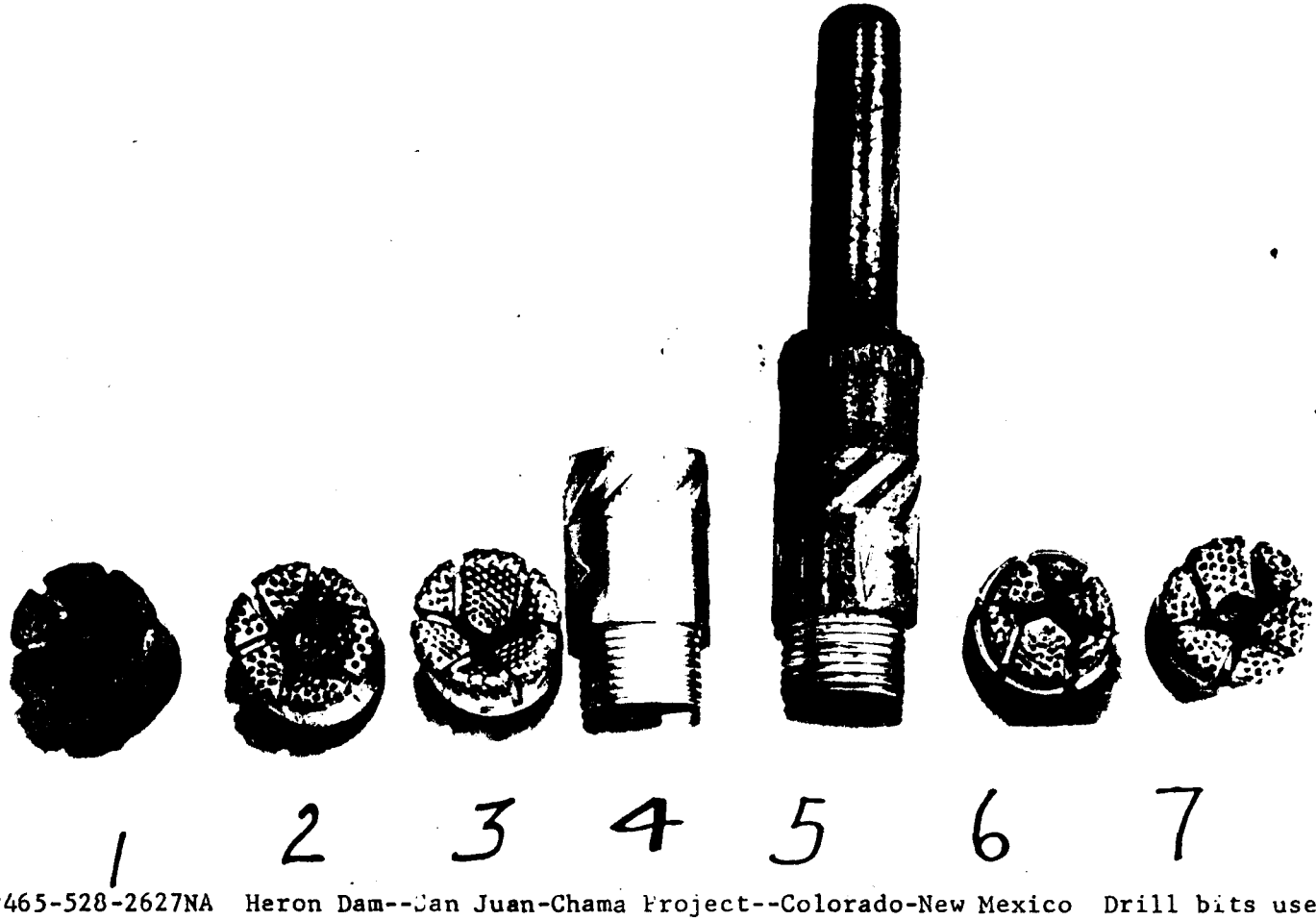
No difficulties were experienced when drilling EX holes with the Chicago-Pneumatic No. 65 drills during drilling operations of the dike, tunnels, and access shaft. AX (1 7/8-inch diameter) holes on the upstream curtain, intermediate curtain, and the 5- and 10-foot pattern closure holes on the main curtain on the dam abutments were also drilled with comparative ease. This was probably due to the fact that grouting the primary holes on the main curtain had stabilized the rock and facilitated secondary drilling to some extent.



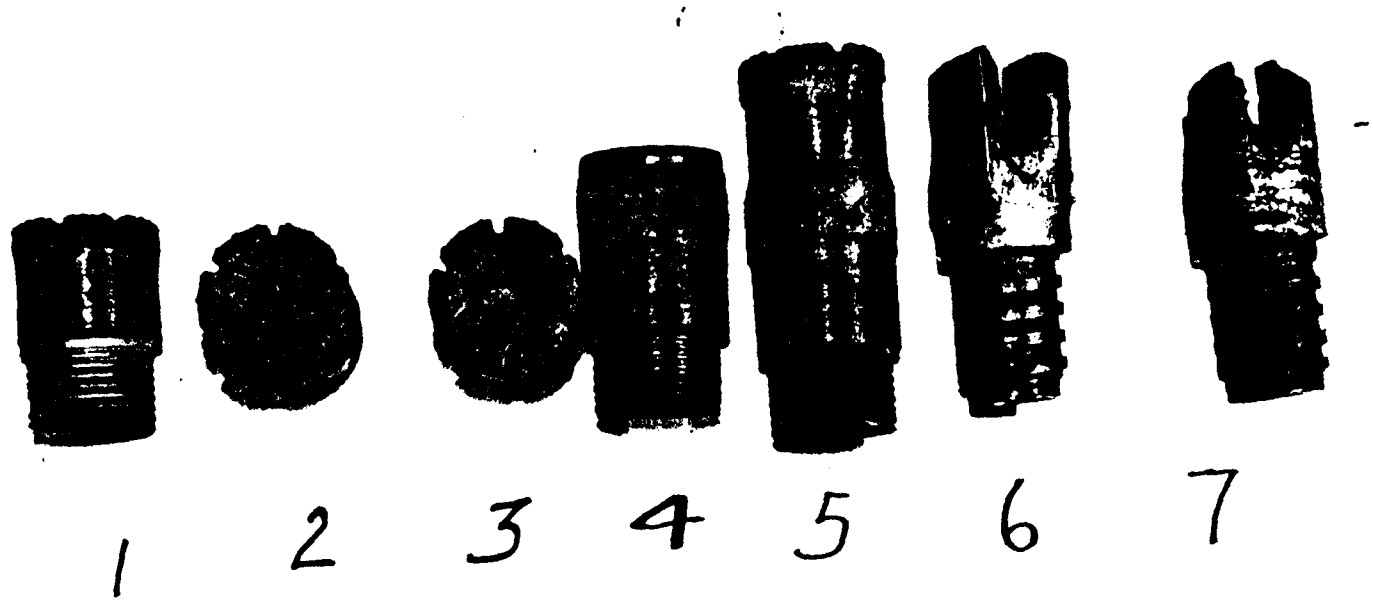
P465-528-2214NA Outlet Works Tunnel-Heron Dam--San Juan-Chama Project--Colorado-New Mexico
Mike Figarelle, an employee of Keltner Drilling Company drills a grout hole with a Chicago Pneumatic No. 65 drill in Heron Dam Outlet Works Tunnel.
Specifications No. DC-6558 Keltner Drilling Company, sub-contractor
5-14-69 Bureau of Reclamation Photo by D. Manning



P465-528-1851NA Heron Dam & Relocation of State Highway No. 95--San Juan-Chama Project--Colorado-New Mexico Vertical view of EX size drill bits being used by Keltner Drilling Company on Heron Dike. From left to right: No. 1: New Fishtail type bit w/three water ways. No. 2: Used Fishtail type bit w/one water way. No. 3: Used Fishtail type bit w/three water ways. No. 4: New Christensen diamond bit w/one water way, 11.35 carats. No. 5: Used Christensen diamond bit w/one water way, approximately 300 lineal feet of drilling. No. 6: Used Christensen diamond bit w/one water way, approximately 600 lineal feet of drilling. No. 7: Almost new Christensen diamond bit w/six water ways, 7.64 carats. No. 8 and 9: Used Christensen diamond bits w/six water ways. Drilled footage unknown. Specifications No. DC-6658 Universal Constructors Inc. sub-contractors Keltner Drilling Company
7-15-68 Bureau of Reclamation Photo by D. Manning



P465-528-2627NA Heron Dam--San Juan-Chama Project--Colorado-New Mexico Drill bits used by Layne Texas on Heron Dam. (1) AX bit (Christensen #A5506) - Drilled 2,833 L.F. "H" Grade diamonds 5 stones per carat. (2) AX bit (Christensen #C2285) "A" Grade diamonds 5 stones per carat. Diamond wt 26.36 carats. (3) AX bit (Christensen #24520) "H" Grade diamonds. 8 stones per carat. (4) AX Resmer Shell B Grade diamonds. 15 stones per carat. Diamond wt 5.50 carats. (5) EX to AX hole opener bit with pilot. (6) AX bit outer edge shoved off after drilling steel. (7) AX bit small crystals of pyrite were found in water ways which caused center of bit to be cored out.
Specifications No. DC-6558 Layne Texas Company, sub-contractor
8-19-70 Bureau of Reclamation Photo by D. Manning



P465-528-2628NA Heron Dam--San Juan-Chama Project--Colorado-New Mexico Drill bits used by Layne Texas on Heron Dam. (1) thru (3) Typical used AX diamond bits. (4) Typical used AX Reamer Shell. (5) Typical used AX bit with reamer shell. (6) New AX three-way drag bit. (7) Used AX three-way drag bit.
Specifications No. DC-6558 Layne Texas Company, sub-contractor
8-19-70 Bureau of Reclamation Photo by D. Manning

When drilling was initiated on the 1,000-foot extended curtain on the right abutment in July 1968, the subcontractor experienced severe difficulties using Chicago-Pneumatic No. 65 drills. It was his contention that the formation in the dam area was quite different from that in the dike area, inasmuch as thick sections of sandstone and shale with sandstone stringers located throughout the shale areas were encountered. These conditions supposedly caused excessive vibration of the drill rods and crawling of the drill bit during penetration. These factors were responsible for the slower rate of penetration and for difficulties encountered in setting leather cup packers.

The subcontractor brought the Reich Model C-350 drill, described earlier, to the jobsite in an effort to overcome these difficulties.

The Reich drill enabled the subcontractor to drill a 2½-inch diameter hole using AW (1 3/4-inch diameter) drill rod to give more hole clearance for the use of pneumatic packers. However, severe difficulties were encountered in drilling with drag-type bits in the second and fourth sandstone members of the Dakota Sandstone, each of which was approximately 20 feet thick (Figure No. 3). The Reich drill was not equipped to drill with diamond bits, so two to three 8-hour shifts were required to drill a single hard sandstone member with drag bits. The remaining sections of Dakota Sandstone could be drilled with relative ease. During the latter stages of the job the Reich drills were modified to use AX (1 7/8-inch diameter) diamond bits and drilling progress improved substantially.

From Station 13+43 to Station 15+61 in the dam foundation all holes were drilled with the Reich Model C-350 drill using the 2½-inch diameter drag bits. The Morrison formation in this area could be drilled with relative ease and drilling rates of 60 feet per hour were common.

Drilling on the abutment slopes was accomplished with Chicago-Pneumatic No. 65 drills primarily drilling AX (1 7/8-inch diameter) holes. Some EX (1½-inch diameter) holes were drilled at several locations; however, the difficulties encountered in setting leather cup packers made the drilling of AX holes and the use of pneumatic packers mandatory. Penetration rates, especially for the primary curtain holes, were usually quite low due to excessive vibration which was mainly due to inexperienced drillers, faulty or inadequate equipment such as crooked drill rods, low water pressure, and low air pressure.

Drilling on the 1,000-foot extended curtain on the left abutment was performed with both the Chicago-Pneumatic and Reich drills.

With the exception of constantly plugging bits, no appreciable difficulties were encountered. The contractor brought a high pressure 4½-inch by 6-inch duplex piston type (Gaso) water pump which was capable of supplying water at 350 psi to the jobsite in March 1970. However, the 2-inch diameter water line laid to supply water for 2 to 4 drills was inadequate.

When drilling and grouting operations were re-initiated on the 1,000 foot extended curtain on the right abutment in July 1970, AX holes were drilled using both the Reich and Chicago Pneumatic No. 65 drills. No difficulties were encountered. The contractor installed a 4-inch diameter water line in conjunction with the high pressure water pump. This supplied a constant volume of water at constant pressure to each drill. The overall drilling rate achieved was 11.7 feet per actual drilling hour which was considerably better than the rate for other areas of the dam. A more significant fact was that for the 12,429 feet of drilling performed during this period, no drilling tools were lost; only one packer with 100 feet of packer pipe was lost, and only six rubber packer elements were ruptured.

The magnitude of drilling difficulties may be summarized in the following general order:

1. Contractor's operations (management) -- such as an inadequate water supply on numerous occasions resulting in insufficient water pressure for drilling from April 1968 to July 1970; use of inexperienced drillers; lack of proper drilling and fishing equipment from April 1968 to September 1969; insufficient supply of compressed air on numerous occasions; and use of inexperienced supervisory personnel from April 1968 to September 1969.

2. Delays caused by mechanical breakdowns of drilling equipment and air compressors.

3. Formation of rock being drilled -- the sandstone-shale layers in some areas made drilling difficult and required more experienced drillers and specialized equipment than was made available.

4. Weather conditions -- the slow rate of progress during the normal construction seasons made it necessary to work through the winter months when winter weather hampered all operations.

Packers

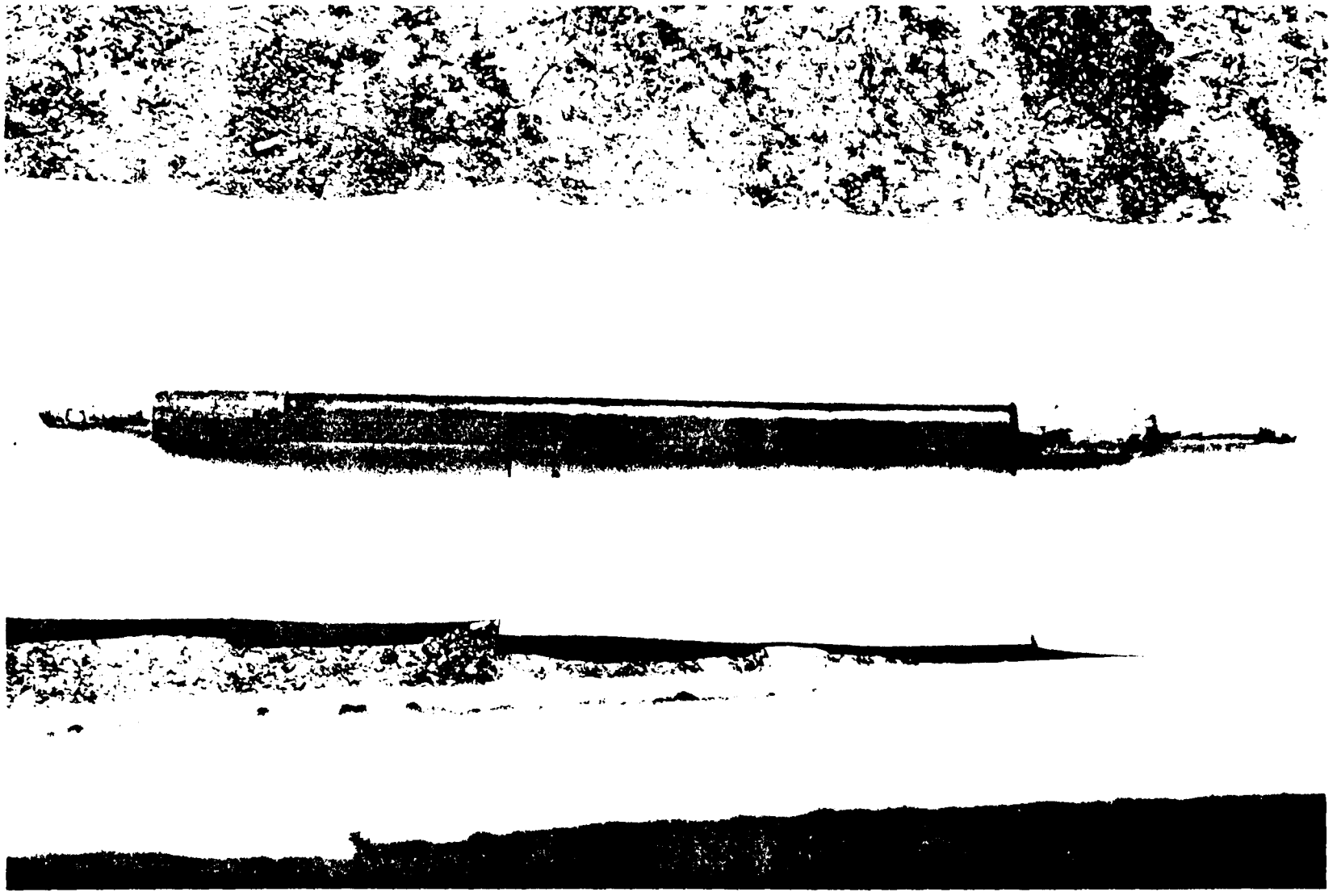
During grouting of the dike, leather-cup packers worked very satisfactorily in EX (1½-inch diameter) drill holes and were used exclusively. However, when drilling was initiated on the 1,000 foot extended curtain on the right abutment in August 1968, considerable difficulty was encountered in setting the leather packers.

The subcontractor then started drilling 2½-inch diameter holes so that BX (2 3/8-inch diameter) pneumatic packers (Photograph No. P465-528-2634NA) could be used. The packers were inflated through 1/8-inch rubber hose with compressed nitrogen (Photograph No. P465-528-2629NA) so the larger hole was needed to provide space for both the nitrogen supply line and the grout supply pipe. Difficulty was experienced by the subcontractor in supplying sufficient nitrogen pressure to the packer without rupturing the packer element and still preventing grout leakage around the packer. It was necessary to apply enough pressure to the packer to overcome the combination of the static head of the grout column, the proposed pumping pressure, and the 50 psi required to expand the packer against the side walls of the grout hole. Unless sufficient nitrogen pressure was supplied to a packer, grout would leak past when the grout pressure reached its maximum psi which was maximum pumping pressure plus the static head of the grout column. Initially, packer elements constructed of rubber of sufficient strength to withstand the required pressures could not be obtained by the subcontractor. Packer elements manufactured by the Apollo Rubber Company, 920 W. Skeely Drive, Tulsa, Oklahoma, constructed from a polyvibrathane material, which was much tougher and more resilient than rubber compounds normally used, were then purchased by the subcontractor. These elements proved very satisfactory at first, but the supplier of the polyvibrathane units became careless in manufacturing the elements so their use was suspended in July 1969. The polyvibrathane material was capable of withstanding pressures as high as 750 psi in areas of competent rock and was very satisfactory if the elements were adequately constructed.

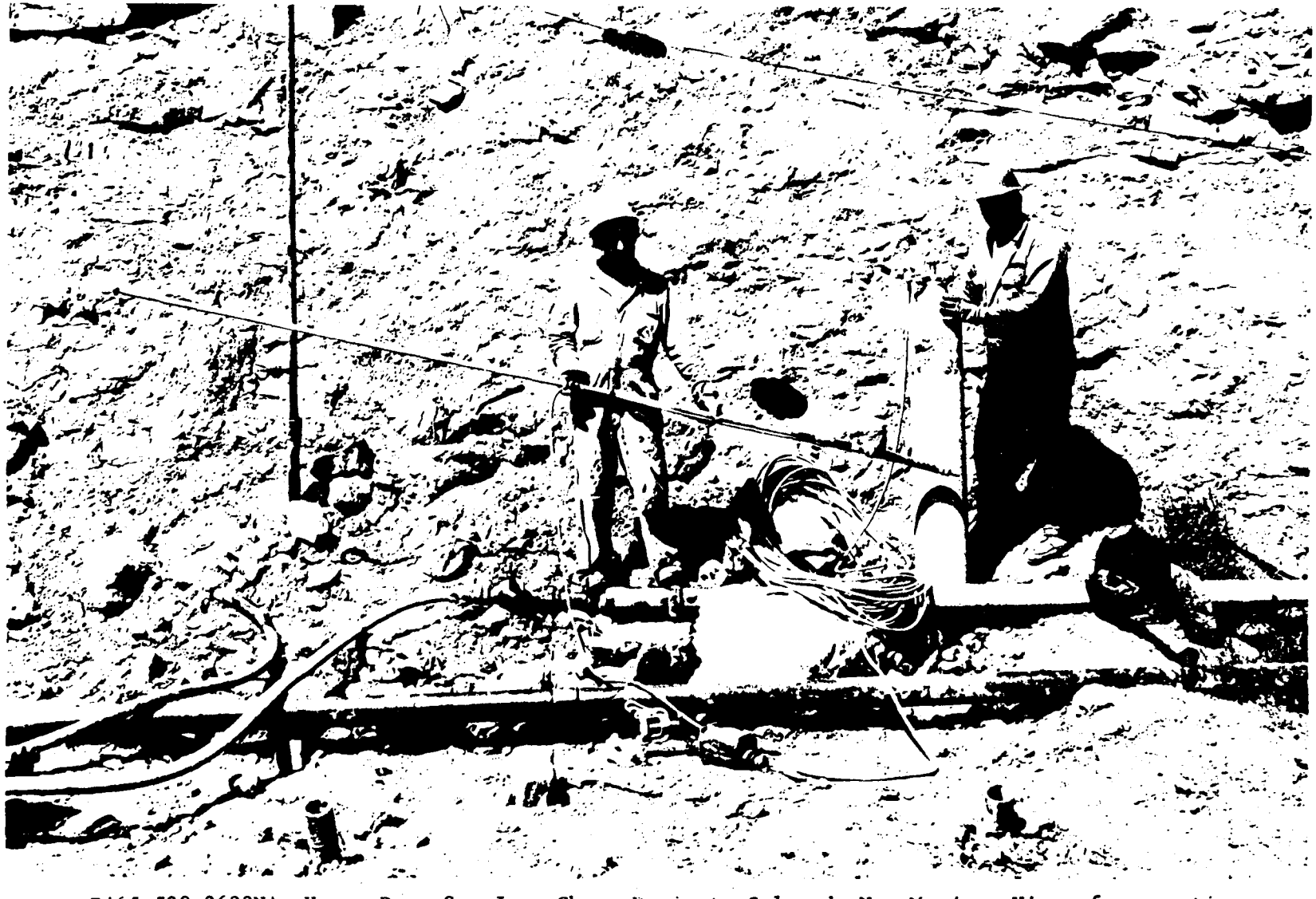
Due to the contractor's difficulty with packers, the grout pressures used were lowered from a maximum of 240 psi to a maximum of 200 psi in October 1968. This maximum was subsequently lowered to 150 psi in February 1969, to enable the contractor to adequately set packers in the holes deeper than 150 feet when difficulties continued to be encountered with a 200 psi maximum grouting pressure.

Packer elements constructed of rubber were purchased from several manufacturers and tried. An element manufactured by Lynes, Inc., 7042 Long Drive, P.O. Box 12486, Houston, Texas, was found to be satisfactory. Rubber elements of different hardness were tested and it was found that rubber of durometer hardness of 50 was the most satisfactory.

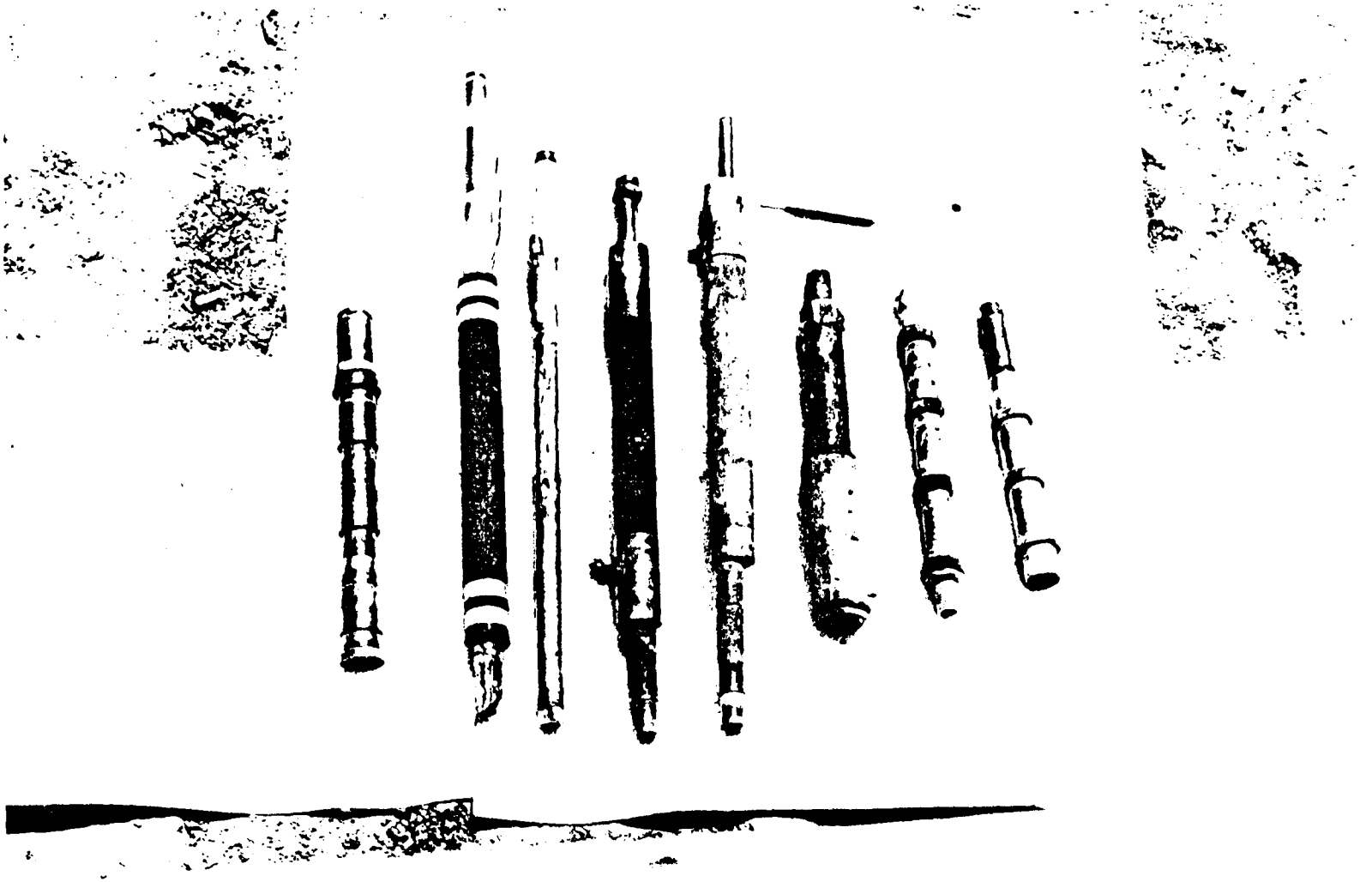
Commercial pneumatic packer frames manufactured by the Damco Manufacturing Company, Dallas, Texas, were used exclusively by the subcontractor from August 1968 to October 1969 (Photograph No. P465-528-2639NA). The disadvantage of these packers was that the AX (2" diameter) packer had only a 3/8-inch diameter opening through the packer. This small opening severely choked flow through the packer. A test run was made to demonstrate to the subcontractor how the small 3/8-inch pipe through the packer restricted the flow of water at different pressures. For instance, total volume was restricted to 11.2 cubic feet in 5 minutes with 88 psi water pressure.



P465-528-2634NA Heron Dam--San Juan-Chama Project--Colorado-New Mexico View of BX pneumatic packer, 1/2" I.D. used on Heron Dam. Packer is manufactured by Dameo Manufacturing Company, Dallas, Texas. Packer element is constructed of poly vibrathane material.
Specifications No. DC-6558 Layne Texas Company, sub-contractor
8-19-70 Bureau of Reclamation Photo by D. Manning



P465-528-2629NA Heron Dam--San Juan-Chama Project--Colorado-New Mexico View of pneumatic packer with 300 lineal feet of 1/4" I.D. rubber hose, compressed nitrogen bottle, regulator and pressure gauges.
Specifications No. DC-6558 Layne Texas Company, sub-contractor
8-19-70 Bureau of Reclamation Photo by D. Manning



P465-528-2639NA Heron Dam--San Juan-Chama Project--Colorado-New Mexico Packers used by Layne Texas Company on Heron Dam. (1) AX Leather cup packer 1" I.D. (2) AX Shop constructed pneumatic packer 3/4" I.D. (3) AX Shop constructed pneumatic packer w/o rubber element 3/4" I.D. (4) AX Pneumatic (Damco) packer 3/8 " I.D. (5) Same as No. 4. (6) AX Squeeze packer 1/2" I.D. (7) EX Leather cup packer 1/2" I.D. (8) Ex Leather cup packer 3/4" I.D.
Specifications No. DC-6558 Layne Texas Company, sub-contractor
8-19-70 Bureau of Reclamation Photo by D. Manning

After October 1969, the subcontractor used shop-constructed packer frames almost exclusively (Photograph No. P465-528-2639NA). The length of the packers varied from 1'0" to 2'6". The 1'0" packers proved more satisfactory than the longer packers.

Most of the difficulties encountered with the packers were the result of faulty construction. On several occasions the small pipe inflating the packer was not properly cleaned when the packer was being assembled, which resulted in the packer not inflating or not deflating thereby making it impossible to remove it from the hole. Careless clamping of the rubber element to the 3/4-inch pipe was responsible for leaks causing the packers to deflate while in the hole.

Excellent results were achieved with the shop-constructed packer when there were no mechanical defects in the packer.

Cement

Cement used for grouting was Type II, low alkali, in accordance with Federal Specifications SS-C-192g, and was manufactured by the Ideal Cement Company, Tijeras, New Mexico. The cement was usually brought directly to the point of use with semi-truck and trailer assemblies hauling 652 sacks per load.

Grout Cap

A grout cap for the main grout curtains was constructed in the foundation rock of the dike and in the foundation rock of the dam. The grout cap trench was excavated by blasting methods through the sandstone and shale members and backfilled with concrete. Some difficulties were encountered in excavation of the trench in the dam between Stations 12+00 and 13+40 on the right abutment and between Stations 15+70 and 17+00 on the left abutment. On the steep sloping abutments, blasting caused extensive fracturing and overbreak in the downslope wall of the grout cap trench.

Grout Pipe Nipples

The grout pipe nipples used were standard black pipe meeting the requirements of Federal Specifications WW-P-406. The pipe was embedded directly in concrete on 10-foot centers in the grout cap. In the outlet works tunnel and access shaft, the grout nipples were set in an alternating pattern on 20-foot centers. Grout nipples required for 5-foot closure holes on the primary curtain and for the upstream curtains were set in grout in percussion-drilled holes. They proved stable if care was used during installation.

Steel casing was set in the Mancos Shale below relocated Highway No. 95 for the 1,000-foot extended curtain on the left abutment. Four inch diameter holes were drilled with a Reich Model C-350 drill using a 4-inch diameter tri-cone roller rock bit. It was

necessary to implant the casing about 15 feet deep for each hole as caving was quite prevalent at shallow depths. The casing was set by filling the hole with a heavy grout and forcing the casing into the hole.

On the right abutment extended curtain, pipe nipples set in grout in holes drilled in the rock were used.

The grout pipe nipples were set at 22 degrees from vertical in the dike foundation, and 24 degrees from vertical in the dam foundation and the 1,000-foot extended curtains.

OUTLET WORKS TUNNEL AND ACCESS SHAFT

Backfill Grouting

Backfill grouting in the outlet works tunnel was performed during February through May 1969. Pipes for the grout and vent holes were placed at high points in the excavated tunnel arch and extended to the form prior to the placement of concrete. After the tunnel lining had been placed the holes were drilled into rock with a jackhammer and water tested as visual inspection showed many of the holes to be tight. Testing was done with water measured through a water meter. One-half cubic foot of water was injected into those holes that accepted water. About 50 percent of the holes were found to be tight.

With exception of the intake structure area, all backfill grout for the tunnel was mixed near the top of the access shaft and pumped to another pump located near the area being backfill-grouted. During backfill grouting of the intake structure area the grout pump was located just outside the portal area. A total of 3,752 sacks of cement in a 1:1 water-cement ratio by volume grout was pumped to backfill behind the concrete in the tunnel, gate chamber, adit to the gate chamber, and intake structure area.

Backfill grouting of the access shaft was performed between elevation 6,985 and elevation 7,173. Liner plate had been installed throughout the shaft. The liner plate was backfilled with concrete between elevation 6,985 and elevation 7,105 by cutting enough holes in the liner plate prior to concrete placement to allow concrete to fill most voids. Grout takes in this section were small and occurred in areas of fallout. The liner plate in the reach between elevation 7,105 and 7,173 had been backfilled with well graded 1½-inch maximum size aggregate. This section was backfill-grouted in a continuous operation by starting at elevation 7,105 and pumping the grout to the next higher set of pipe nipples, and then moving up to that elevation and repeating the operation. The sets of pipe nipples were set in increments of about 10 feet of elevation. The grout was pumped with an air motor-powered Moyno Pump mounted on a moveable platform. The grout was mixed in a plant located at the top of the shaft and then pumped to the lower pump. A total of 1,086 sacks of cement in a 1:1 water-cement ratio by

volume grout was used for all backfill grouting in the shaft. Head phones were used for communication between the two grout plant operators and the hoist operator. See Drawing No. 465-528-1830 for a complete record on backfill grouting.

Backfill grouting of the first stage stainless steel liner plate between Station 10+15 and Station 10+65 was performed during May 1969. The grout mix injected behind the liner plate had a 1:1 water-cement ratio with 2 percent bentonite by weight of cement added. From approximately Station 10+40 to Station 10+62 the one-half inch diameter supply grout holes were tight, however, there were voids under the one-fourth inch diameter vent holes near the center of the liner plate adjacent to the one-half inch diameter supply holes. These voids were grouted through the one-fourth inch diameter vents by injecting grout at 25 psi and then removing the hookup to bleed off the air. This procedure was performed a number of times until no air would return through the grout hole.

Backfill grouting of the second-stage steel liners between Station 9+84 and Station 10+15 was performed in February and March 1970. The grouting procedures used were similar to those used for the first-stage liners. It is recommended that vent and supply holes be a minimum of ½-inch diameter as it is quite difficult to successfully inject grout through ¼-inch diameter holes as was necessary to complete the grouting of the steel liners. A total of 18 sacks and 14 sacks of cement in grout with 2 percent bentonite by weight added to the grout mix were injected into the first-stage and second-stage liners, respectively.

Tunnel and Intake Structure Pressure Grouting

Radial hole grouting in the outlet works tunnel was initiated in March 1969, and continued through June 1969. Grout was mixed near the top of the shaft and pumped to another pump located near the hole being grouted in the outlet works tunnel. Head phones were used between the two grout pump operators for communications. Opposite holes on eighty-foot patterns were drilled and grouted first, followed by the remaining two opposite holes to make closure on each 8-foot pattern grout ring. The procedure was then performed in 40-foot pattern grout rings followed by the 20-foot pattern rings until final closure was achieved. Drawing Nos. 465-D-426, -427, -428, -429, and -430 illustrate the general layout of the grout hole patterns. These patterns were generally pursued except in the intake structure shaft where an extra ring at elevation 6,981 was drilled and grouted to check a badly fractured area and the holes at Station 9+84 were deepened to check the large grout takes at Station 10+04. Large grout takes occurred in the gate chamber area and moderate takes occurred in the intake structure area and in the invert between Station 6+05 and Station 9+25. Grout leaks were almost non-existent although a grout travel of 200 feet was noted on two occasions.

A pumping pressure of 100 psi was used in the gate chamber, adit to the gate chamber, circular section of tunnel upstream of the gate chamber, and the horseshoe tunnel downstream of the gate chamber to Station 11+30. A pumping pressure of 50 psi was used at springline and above and 30 psi below springline downstream of Station 11+30.

Pressures were lowered in the vicinity of the intake structure due to the lack of adequate cover. Packers were not used for the tunnel grouting with the exception of the gate chamber where 60-foot holes were specified. Grout mixtures varied from a 6:1 to 2.5:1 water-cement ratio by volume. The layout and grouting results are shown on Drawing Nos. 465-528-1827, -1828, -1829, and -1835. A total of 9,450 sacks of cement in grout were injected into 4,027.5 lineal feet of drilled hole for an average take of 2.35 sacks per lineal foot of hole.

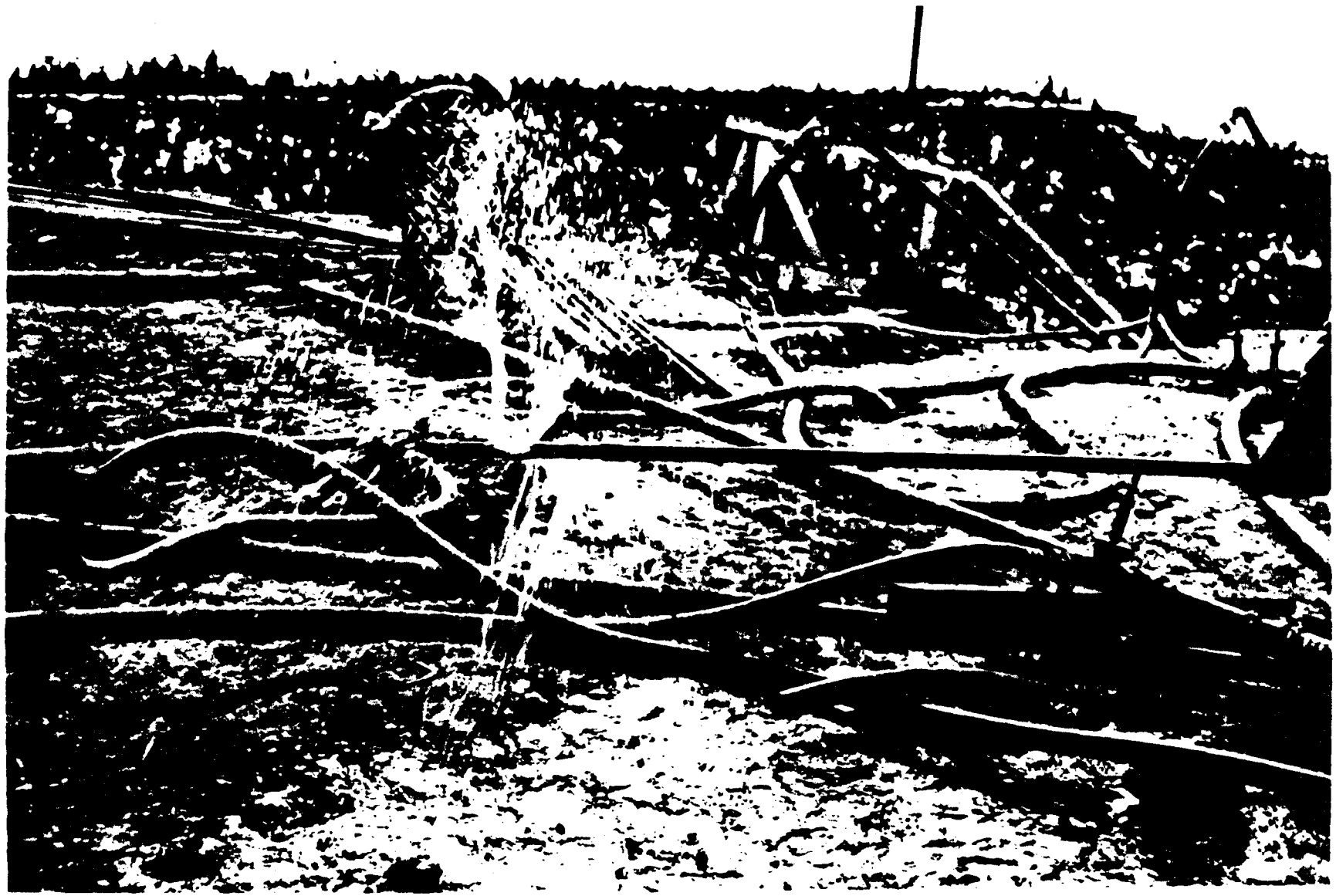
Access Shaft Pressure Grouting

Radial hole drilling was initiated in the access shaft in May 1969, but no grouting was done as operations in the dam foundation required the use of all equipment at that location. Grouting in the access shaft was started in March 1970. The holes drilled in May 1969 were thoroughly washed with a spray device constructed as shown in Photograph No. P465-528-2506NA. Grouting was performed by pumping the grout from the top of the shaft to a header located on a moveable platform located near the grout hole being grouted. Head phones were used between the header man, hoist operator and grout pump operator for communications. All four holes in a ring pattern were drilled on 40-foot centers throughout the shaft. These holes were grouted before the intervening pattern holes were drilled. The west hole at elevation 7,125 and the northeast hole at elevation 7,105 accepted 1,956 and 1,021 sacks, respectively. Both of these holes leaked grout at the surface near the shaft and up to 600 feet upstream from the shaft through two separate vertical joints. These joints seemed to be continuous as grout leaks occurred at intermittent distances on a straight line from the shaft.

Grout mixtures varied from a 6:1 to 1:1 water-cement ratio by volume. A maximum pumping pressure of 100 psi was used in the lower part of the shaft. This pressure was reduced to 10 psi plus 1 psi per foot of rock cover as grouting progressed toward the top of the shaft. The layout and grouting results are shown on Drawing No. 465-528-1832. A total of 3,582 sacks of cement in grout were injected into 806.5 lineal feet of drilled hole for an average take of 4.44 sacks per lineal foot of hole.

Pressure Grouting Concrete in Outlet Works

Pressure grouting of the contraction joints between the first and second stage concrete in the outlet works gate chamber and intake structure was performed in February and October 1970, respectively. The grout was injected through a grout system installed previous to concrete placement as shown on Drawing Nos. 465-D-427 and -429.



P465-528-2506NA Heron Dam--San Juan-Chama Project--Colorado-New Mexico Washing apparatus used to wash the holes in the access shaft that were drilled in May and June 1969, and not grouted until March 1970.
Specifications No. DC-6558 Layne Texas Company, sub-contractor
3-13-70 Bureau of Reclamation Photo by D. Manning

All grout was injected into the lowest grout system and a grout return was received from all the remaining systems and vents. A total of 124 sacks of cement grout was injected into the grout system in the gate chamber at 50 psi with 112 sacks of this in an 0.8:1 water-cement ratio grout mix. The system had a holding pressure of 40 psi at completion. The system was grouted using circulating grout lines, with the grout pump located in the bottom of the access shaft at Elevation 6,962. A total of 60 sacks of grout was injected into the two grout systems in the intake structure at 40 psi with 56 sacks of this in an 0.8:1 water-cement ratio grout mix. The upstream system and downstream system had holding pressures of 25 psi and 30 psi, respectively. These systems were also grouted with circulating grout lines, with the grout pump located near the intake structure inlet.

HERON DIKE

Blanket Grouting

Initially the need for a blanket grouting program in the dike area was not anticipated. However, during the excavation of the spillway open-cut through the Dakota Sandstone, joints and irregular cracks in the area of the proposed grout curtain were opened in the sandstone adjacent to the open-cut (Photograph No. P465-528-1751NA). To stabilize the area two fan holes on each side of the open-cut as shown on Drawing No. 465-528-1797 were drilled and grouted. Additional holes in a circular pattern intercepting the crack on the right side of the spillway open-cut at approximately 8 feet below the rock surface were also drilled and grouted. The joint on the right side extended from Spillway Station 9+60 to Spillway Station 10+33 and was backfilled with a sanded grout and pipes were embedded for vents (Drawing No. 465-528-1796). The grout holes associated with the blanket grouting program consisted of 376 lineal feet of drilling into which 1,647 sacks of cement grout were injected for an average take of 4.38 sacks per lineal foot of drilled hole. All grouting of the B-holes was performed using leather cup packers in conjunction with 3/4-inch diameter black iron grout supply pipe. Grout mixtures varied from a 8:1 to 1:1 water-cement ratio by volume. Most of the grout was a 1:1 mix as grout leaks on the walls of the spillway open-cut were extensive from 50 feet upstream to 200 feet downstream of the grout curtain. In this area, dry portland cement was placed in cracks where leaking occurred and as the cement absorbed water leakage from the crack, a propane torch was used to heat and set the dampened cement. The Sandstone was much too shattered to enable the use of standard caulking materials and methods.

Curtain Holes

Drilling of the deep curtain holes in the dike was begun in April 1968 and completed in July 1968. Drawing No. 465-D-374 illustrates the general layout of the grout hole pattern. This pattern was generally followed with the exception of the area in the Dakota Sandstone where grout takes occurred in the bottom stages of holes drilled to the specified depth. The Dakota formation in the dike area from the top down is comprised of 100 feet of relatively soft sandstone, 10 feet of shale, 20 feet of moderately hard sandstone followed by an undetermined thickness of shale,

P465-528-1751NA Heron Dike--San Juan-Chama Project--Colorado-New Mexico View of relief crack on the upstream side of the grout cap at Dike station 33+55. The crack runs parallel to the spillway open-cut and resulted from blasting for the spillway open-cut. Specifications No. DC-6558 Universal Constructors, Inc.
-24-68 Bureau of Reclamation Photo by D. Manning

dipping 6 degrees in a westerly direction. Of the 4,536 total sacks of cement injected into the curtain holes in the dike, 3,422 sacks were injected into the 100- 140-foot stage which comprises the area of the second sandstone member of the Dakota Sandstone. It is surmised that the second sandstone was more susceptible to fracturing because it was more brittle than the top sandstone at the time of uplift of the North El Vado Dome and less susceptible to healing as the top sandstone is exposed to weathering processes. The remaining 1,114 sacks were injected into the upper sandstone of the Dakota Sandstone and the Mancos Shale. Grout leaks throughout the curtain grouting were minimal. A few leaks occurred in the area near the open-cut spillway and from bedding planes in the Greenhorn Member (limestone) of the Mancos Shale.

Grout mixtures used for the curtain grouting varied from a 10:1 to 1:1 water-cement ratio by volume with most of the grout pumped being 8:1 water-cement ratio. Pressures of 10 to 15 psi at the collar of the hole with increases of one psi per foot depth of packer setting were used. All holes were drilled with a Chicago-Pneumatic No. 65 drill, using EX (1½-inch diameter) diamond plug and drag bits. Leather cup packers were used exclusively. The layout and grouting results are shown on Drawing Nos. 465-528-1797, -1798, -1799, -1801, and -1802.

HERON DAM

Blanket Holes

Thirty-six blanket holes varying in depth from 5 to 40 feet were drilled and grouted in the dam foundation area. Pipe for the blanket holes was embedded in the grout cap concrete where consolidation of the surface rock was deemed necessary before curtain grouting could be initiated. The pipe was embedded to intersect cracks and joints at varying angles and directions. 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.

All grouting of the blanket holes was performed by hooking to the grout pipe collar directly. Grout mixtures varied from a 5:1 to a 1:1 water-cement ratio, with most of the grout being 2:1. Pressures for the blanket hole grouting was limited to 10 psi at the collar of the hole. A total of 5,548 sacks of cement grout was injected into 394 lineal feet of drilled hole for an average take of 14.08 sacks of cement per lineal foot of hole. The layout and grouting results are shown on Drawing Nos. 465-528-1854 and -1855.

Curtain Holes in Foundation

Drilling of the first deep curtain cut-off hole for the foundation was started in November 1968. Curtain hole drilling and grouting was performed continually in conjunction with other

drilling and grouting operations until the final hole was completed in June 1970.

Drawing No. 465-D-372 illustrates the general layout of the grouting pattern used in the curtain grouting. This pattern was generally pursued, except that a "criss-cross" grouting pattern rather than the traditional fan was used in the foundation bottom on the main curtain. Also, no third curtain, 20 feet downstream of the primary curtain as proposed in the specifications, was constructed. The second curtain was stopped at elevation 7,095 on the left abutment and at elevation 7,150 on the right abutment. The second curtain on the right abutment was extended above elevation 7,125 when difficulty in closing 5-foot closure holes above elevation 7,050 on the main curtain in that area was encountered.

Grout mixtures used for the curtain hole grouting varied from 12:1 to 1:1 water cement ratio by volume with most of the grout pumped being 8:1 water-cement ratio. Pressures of 10 to 15 psi at the collar and increased by 1 psi per foot of depth to the packer setting, with a 150 psi maximum, were used. Exceptions to this were between Stations 17+85 and 18+99 where three-fourths psi per foot of depth to packer setting was used on some holes.

Grout leaks during the curtain hole grouting program were extensive between Station 10+00 and Station 11+50 on the right abutment. It was not unusual to have surface leaks through vertical joints, when grout was being pumped in stages 80 to 100 feet in depth. A dotted line from Station 9+72 to Station 12+35 on Drawing No. 465-528-1856 outlines a vertical cross section of an area where all grout holes that accepted more than 1 sack per foot of drilling leaked grout to the surface. Grout leaks were minimal in most other areas. All surface leaks in the foundation bottom and on the right abutment slope were confined to the cut-off trench area. The grout leaks on the right abutment slope were more extensive, but grout leaks on the left abutment occurred over greater distances from the grout curtain. Three holes in the vicinity of Station 17+60 leaked grout 300 to 400 feet downstream when pumping stages 115 to 170 feet deep. The hole at Station 18+12 leaked grout 600 feet downstream above the outlet works tunnel from the 125- 147-foot stage and the hole at Station 17+82 leaked grout 600 feet upstream at the intake structure open-cut from a 22-foot deep, water loss stage. Very few leaks were noted from horizontal bedding planes. Most of the leaks occurred from vertical joints which is verified by the numerous surface leaks from deep packers settings. Grout leaks were usually caulked utilizing dry cement, wooden wedges, empty cement sacks, or burlap, tamped in place with hammers and assorted types of chisels.

Most grout takes appeared to be the result of vertical joints in the sandstone members. The vertical joints were usually normal to the grout curtain which allowed travel upstream and downstream more readily than laterally. It is believed that this uniquity made the numerous 5-foot centers closure holes on the main curtain

a necessity. Some lateral travel was indicated since the average take per linear foot decreased progressively with the closure holes.

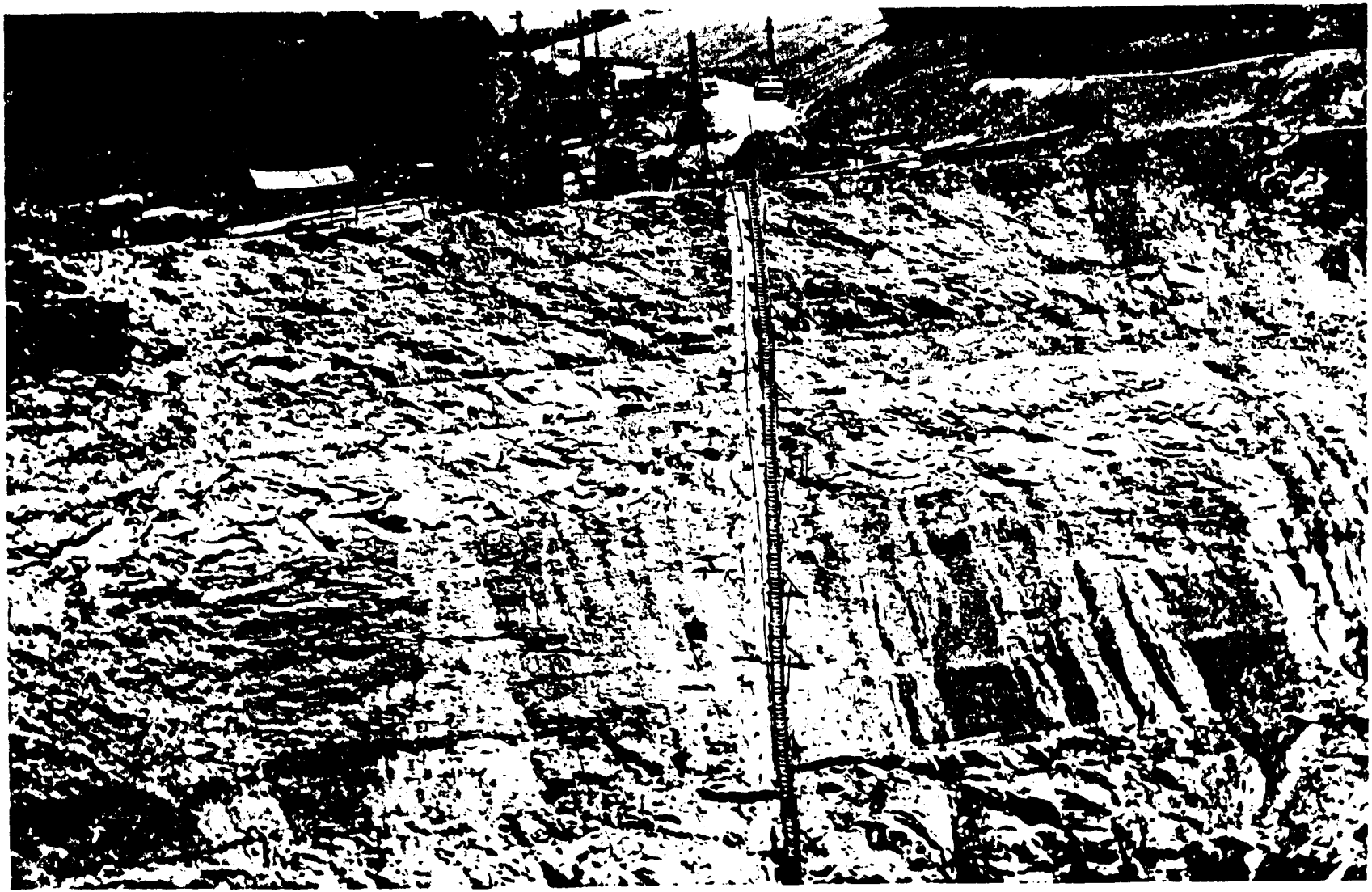
A total of 180 holes on the main curtain, 93 holes on the second curtain 20 feet upstream of the main curtain, and 38 holes 5 to 10 feet upstream of the main curtain were drilled and grouted. For a complete breakdown of grout takes, see Figure No. 2 on Page 39.

The grout curtains were designed for holes on 10-foot centers and original pattern holes on the main curtain were drilled on 80-foot centers. The holes for curtain No. 2 were advanced on 40-foot patterns up the slope, 80 feet behind the completed main curtain.

Holes 10 feet upstream of the main curtain were drilled and grouted at locations where significant grout takes occurred in the second curtain or in the 5-foot closure holes on the main curtain.

On April 28, 1970, while grouting the 20- to 40-foot stage in the main curtain hole at Station 18+20 on the left abutment, a vertical joint was opened. This joint opened approximately ¼-inch 75 feet upstream of the grout cap, 1/8-inch at the grout cap, and 3/4-inch 80 feet downstream of the grout cap where it terminated in a silt and root filled crack. The joint crossed the grout cap at Station 18+38 in a direction sub-parallel to the contour of the slope and essentially parallel to the main set of steep joints which strike N 25 E and dip 80° W (downslope). The joint was opened further on May 10, 1970, while grouting the 20- to 40-foot stage in the hole at Station 18+16 and again on May 18, 1970, while grouting the 0 to 10-foot stage in the hole at Station 18+32 (10' upstream), Drawing No. 465-528-1866. Extreme precautions were used with pressures and mixes on the last occasion. Precision levels disclosed a maximum uplift of 0.13 feet at Station 17+89 with no uplift above Station 18+35, and 0.05 feet uplift below Station 17+66. To prevent further movement, grouting operations were suspended and 12 each 1-inch diameter rock bolts 20 to 24 feet in length were installed through the joint in the area near the grout cap as shown on Photograph No. P465-528-2593NA. Seven holes were drilled through the joint and grouted after the rock bolts had been installed. No further horizontal or vertical movement occurred after the rock bolts had been installed and grouting of the seven holes completed.

The largest grout take for any single hole occurred in the main curtain hole at Station 10+73 on the right abutment. A total of 6,609 sacks of cement were injected throughout the hole in which 11 separate water losses had occurred. Most of the grout takes, in this hole as in most other holes throughout the grouting program, were characteristically slow. The necessity of using thin grout mixes prolonged some grout takes to as long as 12 days for a single stage. High water to cement ratios were required because mixes thicker than 6:1 water-cement ratio by volume could normally not be injected when the grout take was less than 12 to 15 sacks per hour. Experimenting with thicker mixes was tried on numerous occasions without sucess.



P465-528-2593NA Heron Dam and Relocation of State Highway No. 95--San Juan-Chama Project--Colorado-New Mexico View of the rockbolts pattern on the left abutment of Heron Dam. Bolts were installed through a joint in the sandstone which was opened while grouting the 20-40 foot stage in the hole at station 18+20 on the grout cap. The rockbolts are 20 to 24 feet long and were installed near the center of the photo.
Specifications No. DC-6558 Universal Constructors, Inc.
6-19-70 Bureau of Reclamation Photo by D. Manning

The layout and grouting results for the foundation grouting are shown on Drawing Nos. 465-528-1847, -1848, -1849, -1852, -1853, -1856, -1857, and -1866.

Curtain Holes in 1,000-foot Curtain Right Abutment

Drilling and grouting operations were initiated on the 1,000-foot extended curtain on the right abutment of Heron Dam in July 1968, and progressed intermittently until completion in August 1970 (Photograph No. P465-528-2631NA). Drawing No. 465-D-372 illustrates the general layout of the grout hole pattern.

A total of 112 holes were drilled and grouted. These holes accepted 15,458 sacks of cement grout in 17,130 lineal feet of drilled hole for an average take of 0.90 sack of cement per lineal foot of drilled hole. Grout mixtures used varied from 8:1 to 1:1 water-cement ratio by volume with most of the grout pumped being 8:1 water-cement ratio. Pressures of 10 psi at the collar with increases of one psi per foot of depth to packer setting were used.

Grout leaks were almost non-existent with the exception of the hole at Station 3+00 (52' water loss) which leaked grout from a continuous vertical joint striking north-south. The leak extended from 50 feet south of the hole (downstream) to 300 feet north of the hole (upstream).

The grout curtain was designed for holes on thirty-foot centers and original pattern holes were drilled 120 feet apart. Several patterns required holes on seven and one-half foot centers to attain closure with practically all patterns requiring holes on fifteen foot centers to attain closure. Only thirteen water losses occurred in the 17,130 feet drilled. The layout and grouting results for the 1,000 foot extended curtain on the right abutment are shown on Drawing Nos. 465-528-1817, -1823, and -1856.

Curtain Holes in 1,000-foot Curtain Left Abutment

Drilling of the first hole on the 1,000-foot extended curtain on the left abutment was started in April 1970, and drilling and grouting operations continued until completion in July 1970 (Photograph No. P465-528-2566NA). Drawing No. 465-D-372 illustrates the general layout of the grout hole pattern. This pattern was generally followed except that between Station 18+29 and Station 20+54 back, the curtain was constructed upstream of the access shaft and gate chamber to give added protection to these facilities.

A total of 127 holes were drilled and grouted. These holes accepted 42,686 sacks of cement grout in 18,885 lineal feet of drilled hole for an average take of 2.26 sacks of cement per lineal foot of drilled hole. Grout mixtures used varied from 15:1 to 1:1 water-cement ratio by volume with most of the grout pumped being 8:1 water-cement ratio. Pressures of 10 psi at the collar with increases of one psi per foot of depth to packer setting with a maximum of 150 psi were used.

P465-528-2631NA Heron Dam--San Juan-Chama Project--Colorado-New Mexico General view of grouting operations on the 1,000 foot extended curtain on the right abutment at Heron Dam. Viewing in an easterly direction from station 6+50.
Specifications No. DC-6558 Layne Texas Company, sub-contractor
8-19-70 Bureau of Reclamation Photo by D. Manning

P465-528-2566NA Heron Dam--San Juan-Chama Project--Colorado-New Mexico General view of the 1,000 foot extended grout curtain on the left abutment of Heron Dam. Grout plant in the foreground is located at station 26+25.
Specifications No. DC-6558 Layne Texas Company, sub-contractor
4-11-70 Bureau of Reclamation Photo by D. Manning

Grout leaks occurred from several holes, however, little caulking was required as the leaks usually occurred above elevation 7,190 and in close vicinity to the hole being grouted. Water seeps were noted above the second sandstone member of the Dakota Sandstone on the service road to the outlet works about 600 feet downstream from the grout curtain. Water losses were quite common in the Mancos Shale which rests on the Dakota Sandstone, however, grout takes were usually small. Numerous grout mixes were tried varying from 3:1 to 15:1 water-cement ratio by volume. The thinner mixes were more successful in sealing off these re-occurring water losses.

The largest grout take for a stage for all grouting on the dam or dike occurred in the hole at Station 20+36. A total of 4,136 sacks was injected into a partial water loss area 240 feet deep (elevation 6,960). The water loss occurred approximately 120 feet from the access shaft and some slight grout returns were noted from radial holes in the shaft at elevation 7,025 and elevation 7,045. Other large takes occurred in the first member of the Dakota Sandstone immediately beneath the Dakota Sandstone-Mancos Shale contacts which is in direct contrast to the 1,000-foot extended curtain on the right abutment. This is attributed to the fact that the joints in the sandstone on the left abutment had been continuously covered and not exposed to the weathering process, so had no chance of being filled as did those in the other areas.

The grout curtain was designed for holes on thirty foot centers and original pattern holes were drilled 120 feet apart. Several patterns required holes on 3.75-foot centers to attain closure with all patterns requiring holes on fifteen foot centers to attain closure. Approximately 105 water losses occurred in the 18,855 feet drilled with the majority of the water losses occurring in the Mancos Shale Formation. The layout and grouting results for the 1,000-foot extended curtain on the left abutment are shown on Drawing Nos. 465-528-1864 and -1865.

Claims

The subcontractor for grouting, Layne-Texas Company, has filed a claim through the prime contractor, Universal Constructors, Inc., for additional compensation because of alleged changed conditions causing drilling to be more difficult and grout takes slower than had been anticipated. Disposition of the claim will be covered in the final construction report on Heron Dam.

Figure No. 1

SUMMARY OF QUANTITIES AND EARNINGS

Item No.	Nature of Work	Quantity	Earnings
9.	Excavation for grout caps to 5 feet in depth	1,863 cu. yd.	$ 16,767.00
10.	Excavation for grout caps between depths of 5 and 8 feet	40 cu. yd.	480.00
39.	Drilling drainage holes in tunnel lining	1,210 lin. ft.	6,050.00
40.	Mobilization and demobilization for drilling and grouting foundations	100%	90,000.00
	Drilling grout holes in stage between the following depths:		
41.	0 and 30 feet (rock)	24,717.5 lin. ft.	73,873.25
41.	0 and 260 feet (redrill)	2,145.5 lin. ft.	
42.	30 and 60 feet	17,340.0 lin. ft.	47,685.00
43.	60 and 110 feet	24,265.0 lin. ft.	66,728.75
44.	110 and 160 feet	18,558.0 lin. ft.	51,034.50
45.	160 and 210 feet	12,255.0 lin. ft.	33,701.25
46.	210 and 260 feet	6,821.0 lin. ft.	23,873.50
47.	Drilling and casing holes through overburden on left abutment	1,065.0 lin. ft.	12,780.00
48.	Furnishing and placing pipe and fittings for grouting foundations	14,514.5 lbs.	7,257.25

Item No.	Nature of Work	Quantity	Earnings
49.	Hookups to grout holes and connections	1,033 ea.	$15,495.00
50.	Pressure grouting foundations in accordance with Paragraph 99.c. of the specifications		
	(a) Grout take of 1.25 cubic feet per linear foot of drilled hole	131,277 cu. ft.	262,554.00
	(b) Grout take in excess of 1.25 cubic feet per linear foot of drilled hole	28,749 cu. ft.	28,749.00
51.	Furnishing and handling cement for pressure grouting	40,228.5 bbl.	261,485.25
52.	Pressure grouting concrete in outlet works intake structure and gate chamber	100%	20,000.00
64.	Cement for concrete and backfill grouting	3,180.5 bbl.	20,673.25
69.	Concrete in grout caps	1,634.9 cu. yds.	57,221.50
	Order for Changes No. 3 - Rockbolts	264 lin. ft.	2,590.92
		TOTAL GROUTING EARNINGS	$1,098,999.42

Sheet 1 of 2

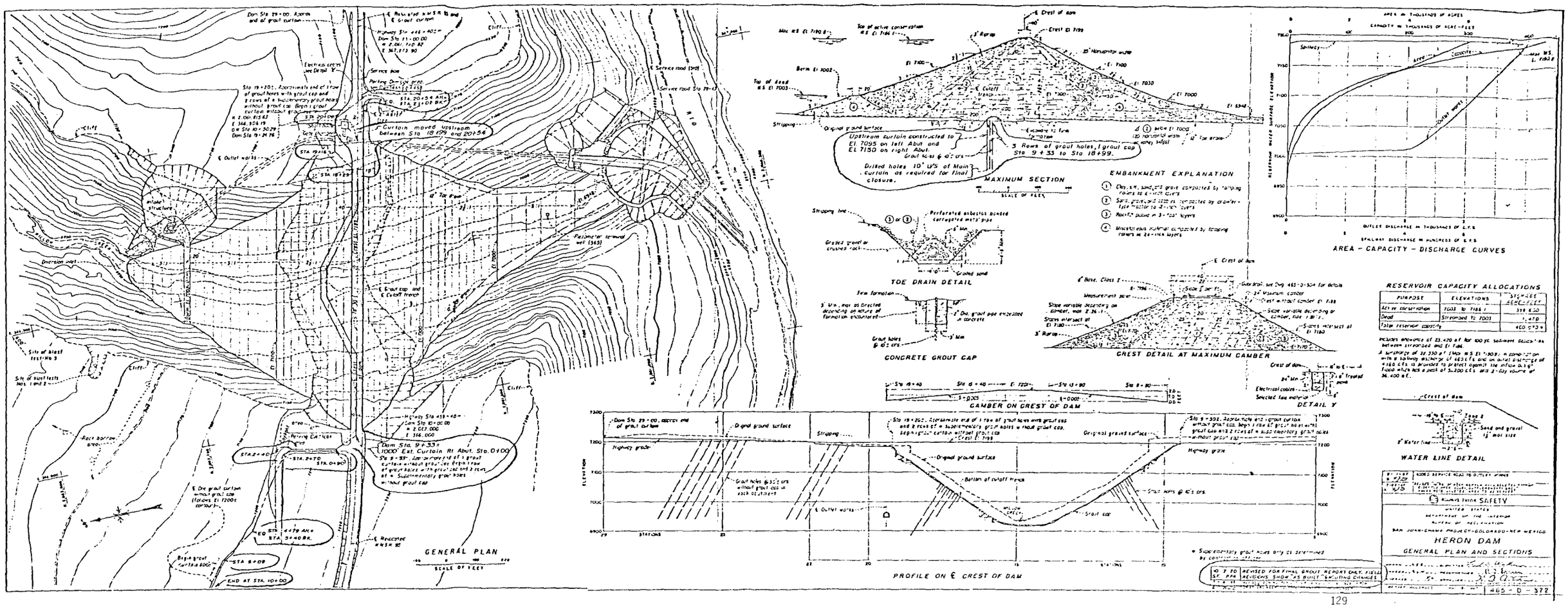
Figure No. 2

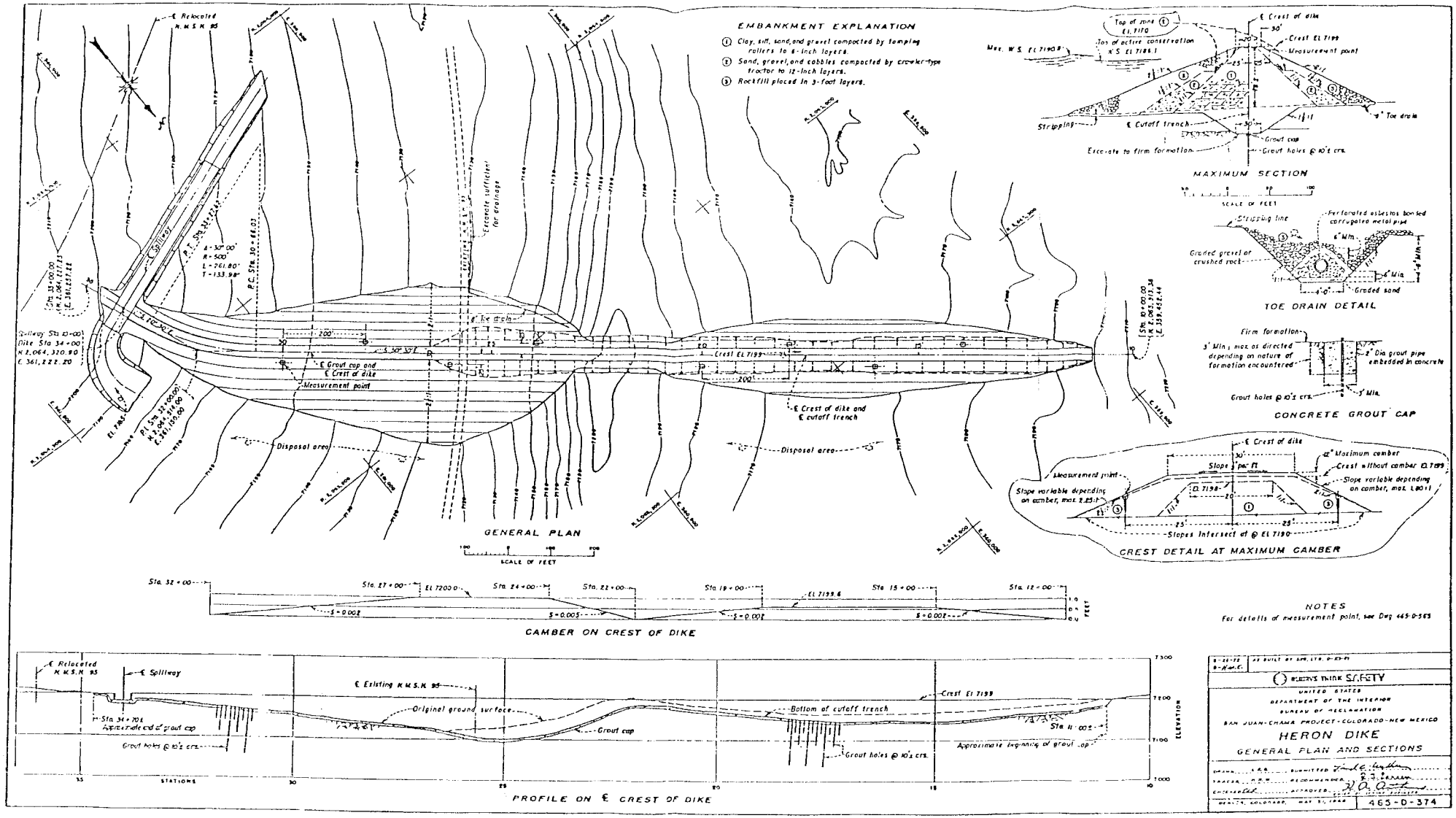
SUMMARY OF HERON DAM AND DIKE PRESSURE GROUTING

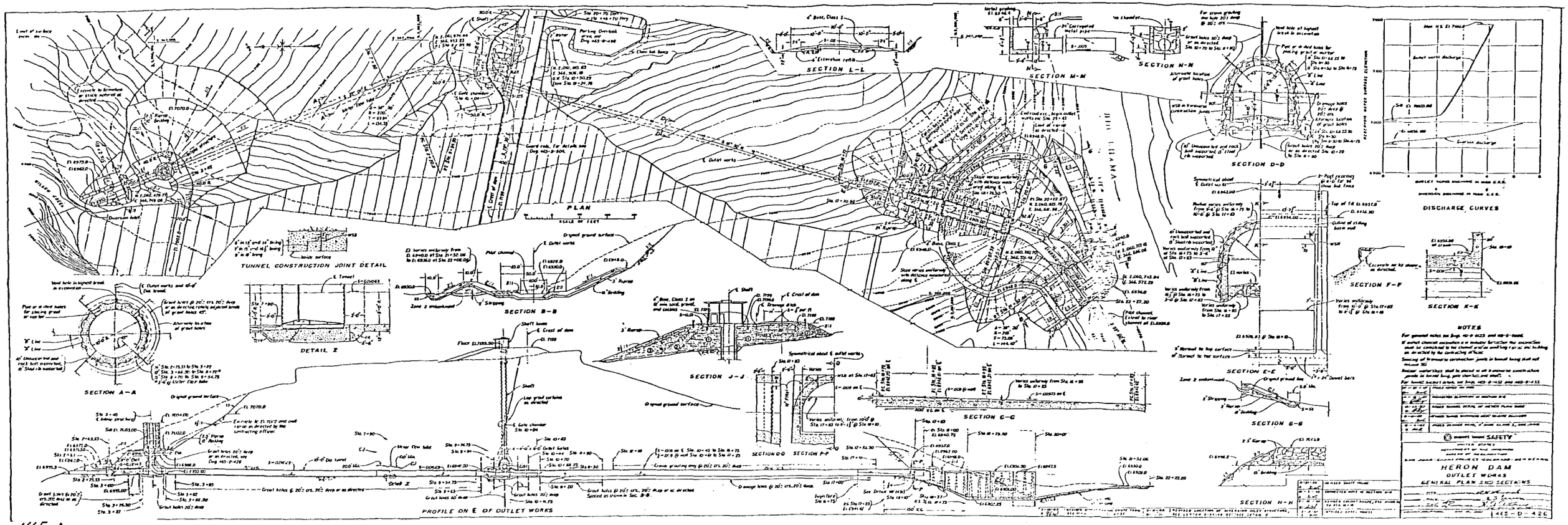
	Final Quantities		
	Lin.Feet Drilled	Cement Take No. Sacks	Cement Take Sacks/Ft.
HERON DAM FOUNDATION			
Main Curtain			
Original Holes (80' Centers)	3,261.5	29,704	9.11
First-Closure Holes (40' Centers)	2,705.5	15,205	5.62
Semi-Closure Holes (20' Centers)	5,649.5	14,024	2.48
Final-Closure Holes (10' Centers)	10,264.0	7,948	0.77
Additional-Closure Holes (5' Centers)	9,349.0	5,303	0.57
Main Curtain Total	31,229.5	72,184	2.31
Upstream Curtain (No. 2)			
Original Holes (40' Centers)	3,908	1,913	0.49
Semi-Closure Holes (20' Centers)	3,440	1,037	0.30
Final-Closure Holes (10' Centers)	2,764	910	0.33
Additional-Closure Holes (5' Centers)	160	0	0.00
Upstream Curtain Total	10,272	3,860	0.38
Intermediate Closure Holes between Curtains	4,220	488	0.12
Blanket Holes	394	5,548	14.08
Total for Dam Foundation	46,115.5	82,080	1.78
HERON DIKE FOUNDATION			
Original Holes (80' Centers)	3,651	1,783	0.49
First-Closure Holes (40' Centers)	3,439	983	0.29
Semi-Closure Holes (20' Centers)	4,797	1,023	0.21
Final-Closure Holes (10' Centers)	4,579	737	0.16
Additional-Closure Holes (5' Centers)	150	10	0.07
Dike Curtain Total	16,616	4,536	0.27
Fan Holes in Spillway Open Cut	148	553	3.74
Angle Holes intercepting relief crack	160	779	4.87
Vent Holes located in relief crack	68	346	5.09
Total for Dike Foundation	16,992	6,214	0.37

Figure No. 2 sheet 2 of 2

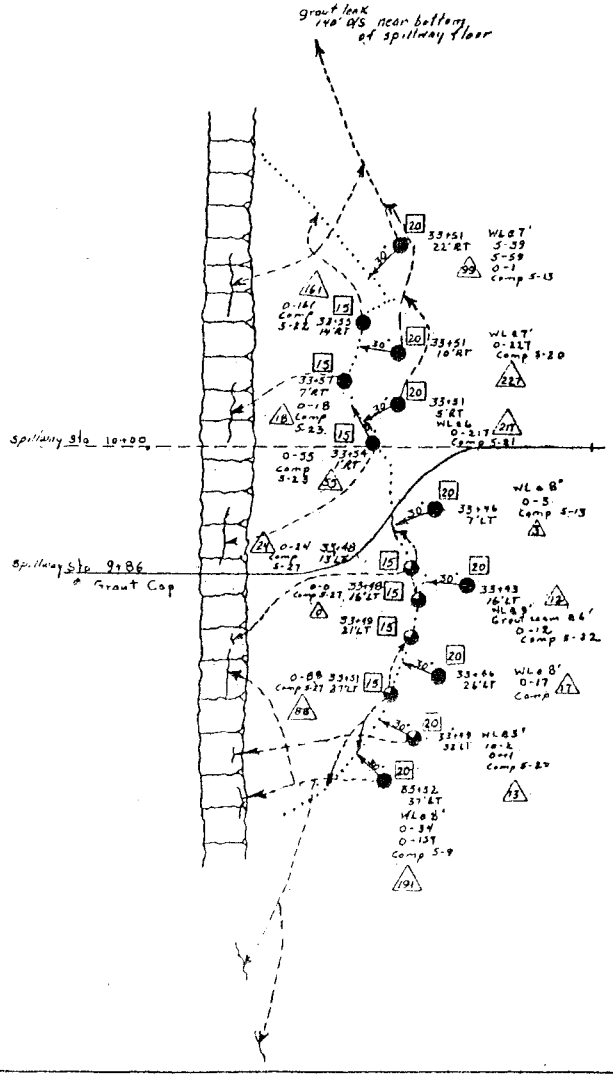
	Final Quantities		
	Lin.Ft. Drilled	Cement Take No. Sacks	Cement Take Sacks/Ft.
1000' EXTENDED CURTAINS			
Right Abutment			
Original Holes (120' Centers)	2,306	6,489	2.81
First-Closure Holes (60' Centers)	2,080	3,441	1.65
Final-Closure Holes (30' Centers)	4,417	3,106	0.70
Additional-Closure Holes (15' Centers)	6,497	2,235	0.34
Additional-Closure Holes (7.5' Centers)	1,830	187	0.10
Rt. Extended Curtain Total	17,130	15,458	0.90
Left Abutment			
Original Holes (120' Centers)	2,409	19,468	8.08
First-Closure Holes (60' Centers)	2,139	7,791	3.64
Final-Closure Holes (30' Centers)	4,339	9,790	2.26
Additional-Closure Holes (15' Centers)	6,840	4,722	0.69
Additional-Closure Holes (7.5' Centers)	2,768	902	0.33
Additional-Closure Holes (3.75' Centers)	390	13	0.03
Lt. Extended Curtain Total	18,885	42,686	2.26
Access Shaft Radial Holes	806.5	3,582	4.44
Adit to Gate Chamber Radial Holes	70	0	0.00
Outlet Works Tunnel Radial Holes	3,957.5	9,450	2.39
Cement used for Backfilling Grout Holes	-	556	-
Drilling for Casing through Overburden	1,065.0	-	-
Contract Total (Final)	105,021.5	160,026	1.52

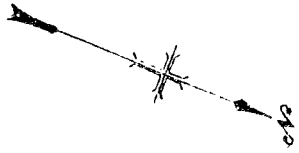

GENERAL PLAN
SCALE OF FEET
MAXIMUM SECTION
EMBANKMENT EXPLANATION
TOE DRAIN DETAIL
CONCRETE GROUT CAP
CREST DETAIL AT MAXIMUM CAMBER
CAMBER ON CREST OF DAM
DETAIL Y
AREA - CAPACITY - DISCHARGE CURVES
RESERVOIR CAPACITY ALLOCATIONS
WATER LINE DETAIL
PROFILE ON ℄ CREST OF DAM
SAN JUAN-CHAMA PROJECT-COLORADO-NEW MEXICO
HERON DAM
GENERAL PLAN AND SECTIONS
465-D-372


EMBANKMENT EXPLANATION
1 Clay, silt, sand, and gravel compacted by tamping rollers to 6-inch layers.
2 Sand, gravel, and cobbles compacted by crawler-type tractor to 12-inch layers.
3 Rockfill placed in 3-foot layers.
GENERAL PLAN
SCALE OF FEET
MAXIMUM SECTION
TOE DRAIN DETAIL
CONCRETE GROUT CAP
CREST DETAIL AT MAXIMUM CAMBER
CAMBER ON CREST OF DIKE
PROFILE ON ℄ CREST OF DIKE
STATIONS
ELEVATION
NOTES
For details of measurement point, see Dwg 465-D-563
HERON DIKE
GENERAL PLAN AND SECTIONS
465-D-374



465-D-426 FRAME 2





EXPLANATION

- 20 -- Depth of hole
- -- Location
- -- Nipple Set
- -- Hole Drilled
- -- Grouted This Month
- -- Grouted Previous Month

Depth of Packer Setting --- 10-34 -- Grout Take - (Sacks)

- Grout Travel from hole
- WL@16' Water loss depth
- 30° Angle from Vertical
- 6856 Elevation of hole
- Outline of open crack
- Vents placed in crack
- Sacks Taken

G ing Progress as of June 25, 1968

Scale - 1" = 10'

ALWAYS THINK SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN - CHAMA PROJECT - COLORADO - NEW MEXICO

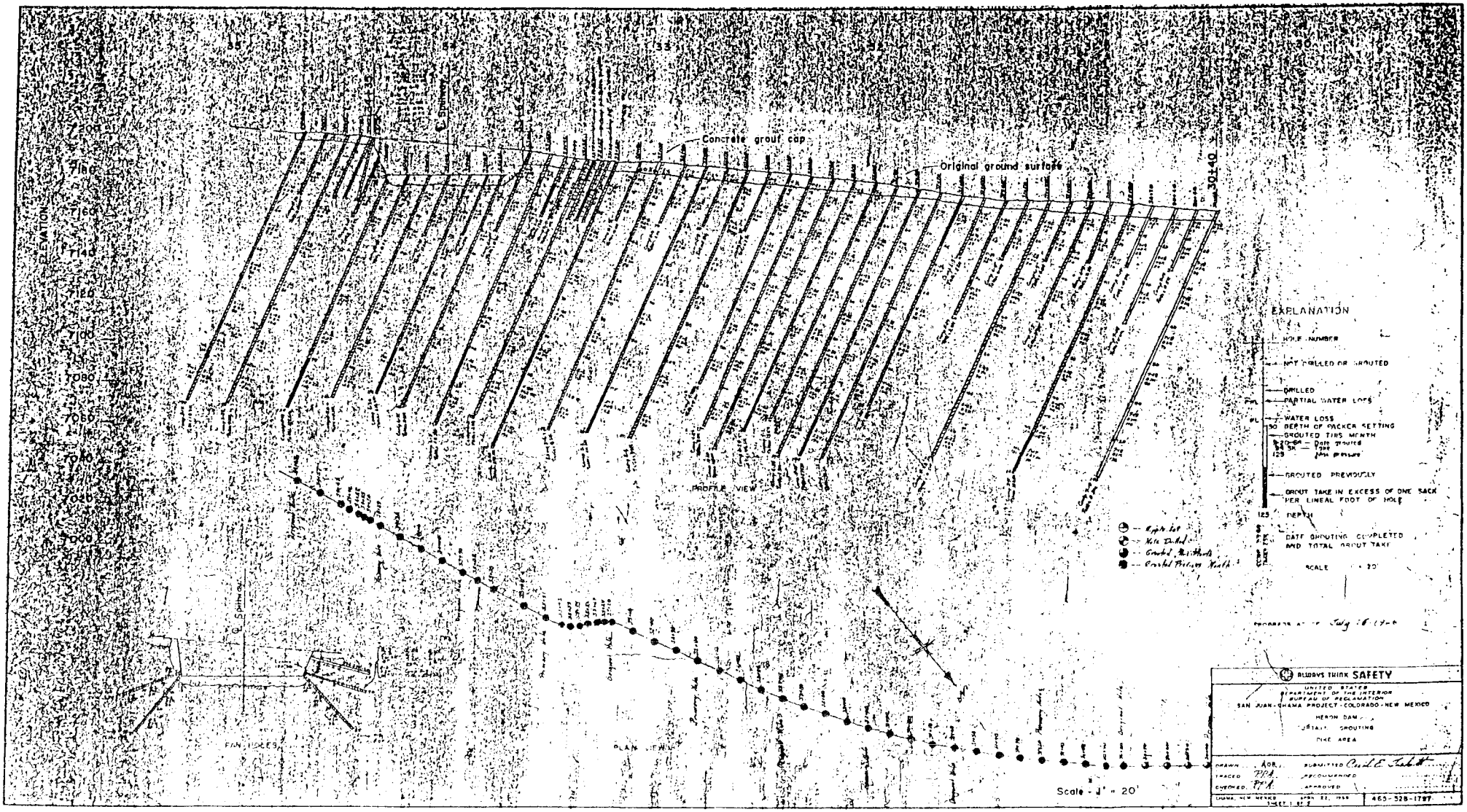
HERON DAM

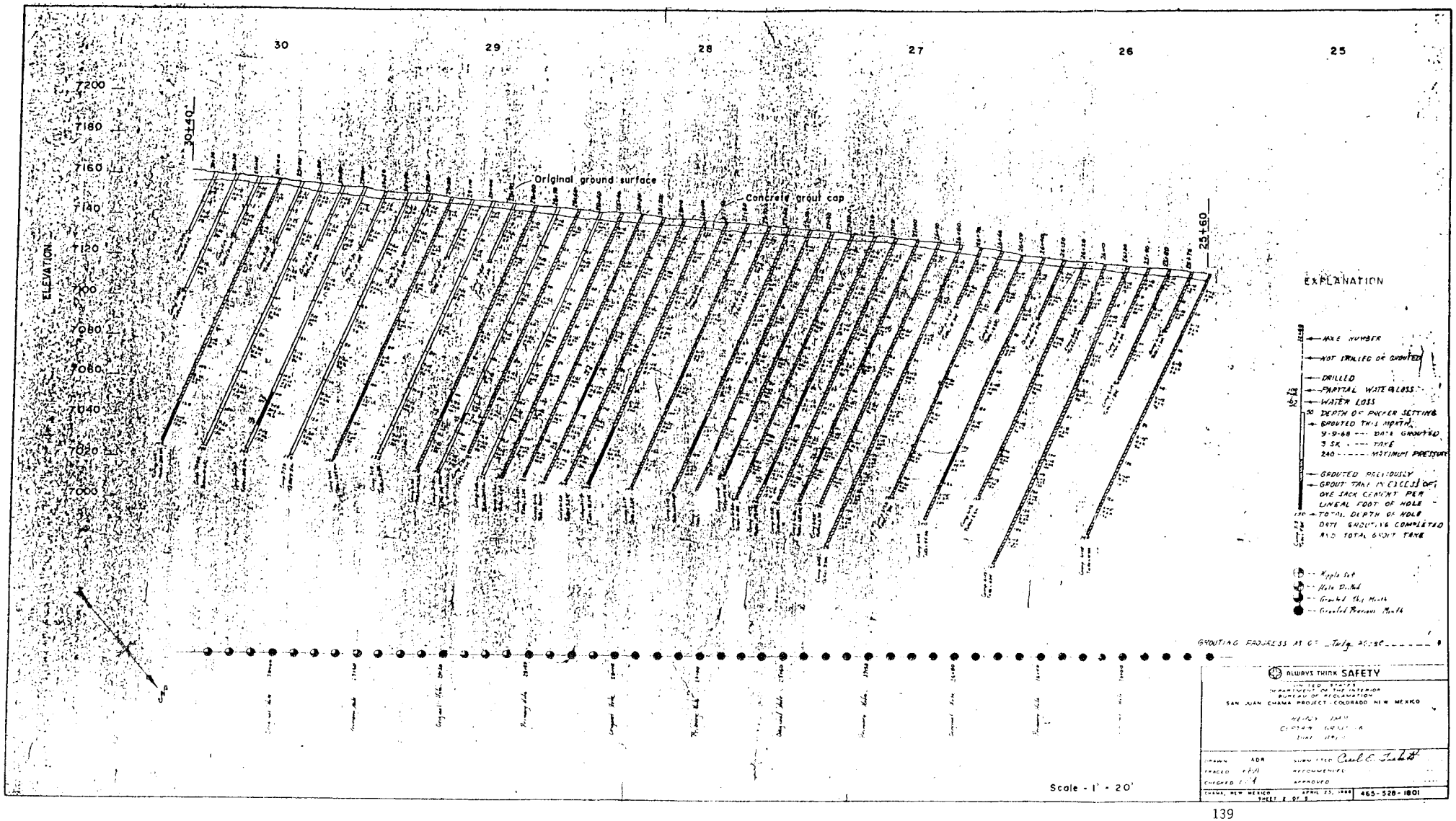
FOUNDATION GROUTING
DIKE AREA

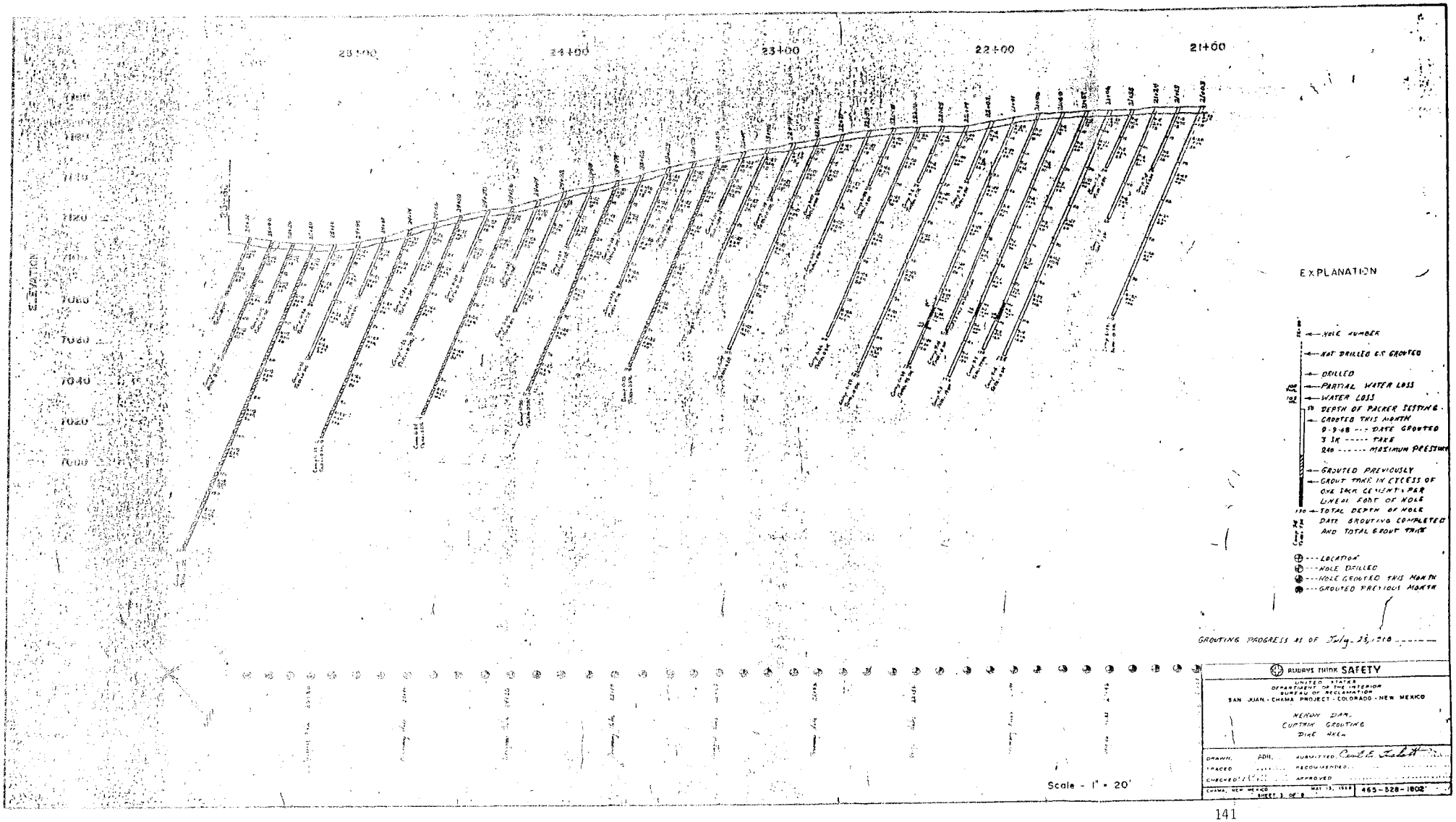
RELIEF - RACK ON RIGHT SIDE OF SPILLWAY

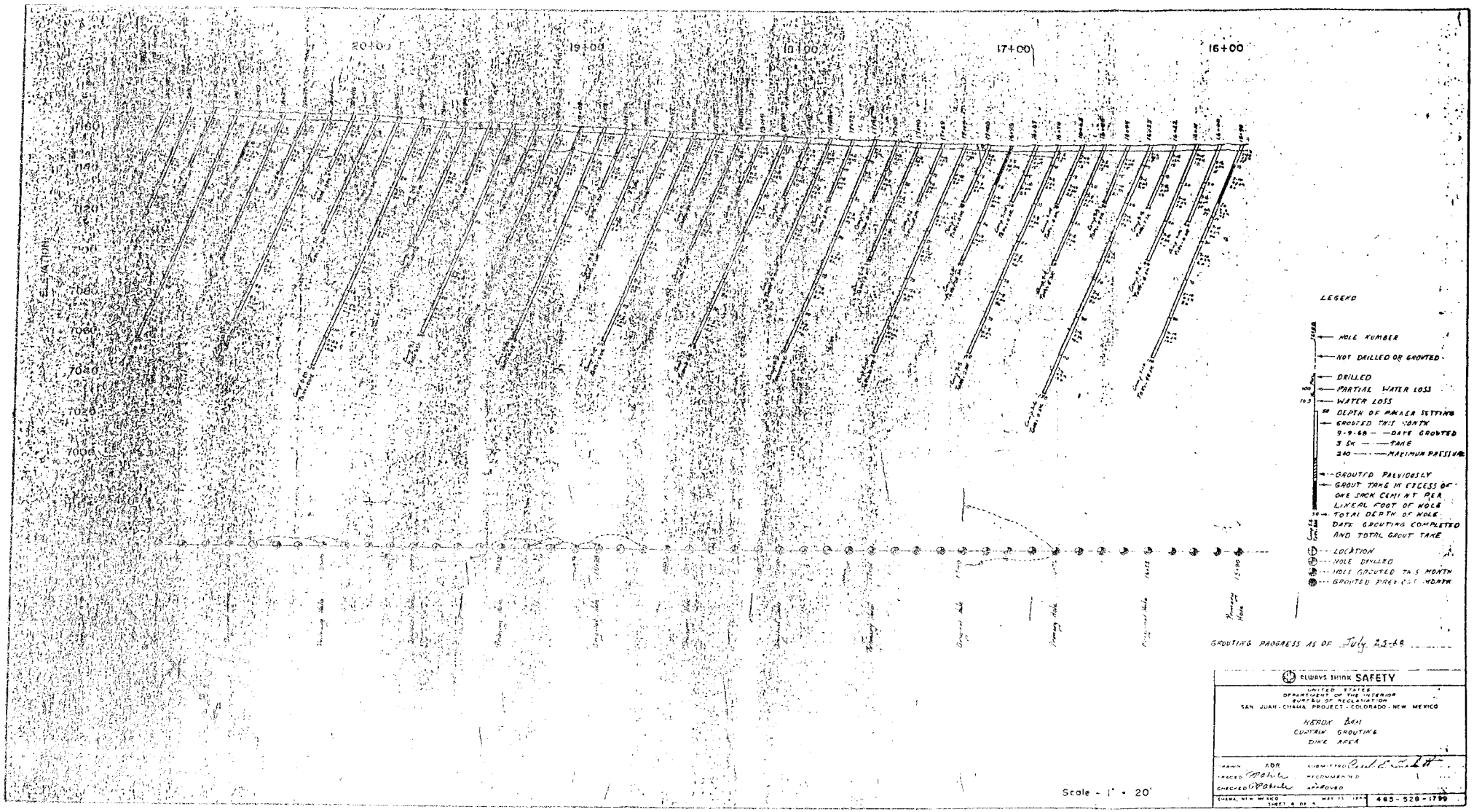
DRAWN P.P.A. SUBMITTED Cecil E. Tuckett
TRACED P.P.A. RECOMMENDED
CHECKED P.P.A. APPROVED

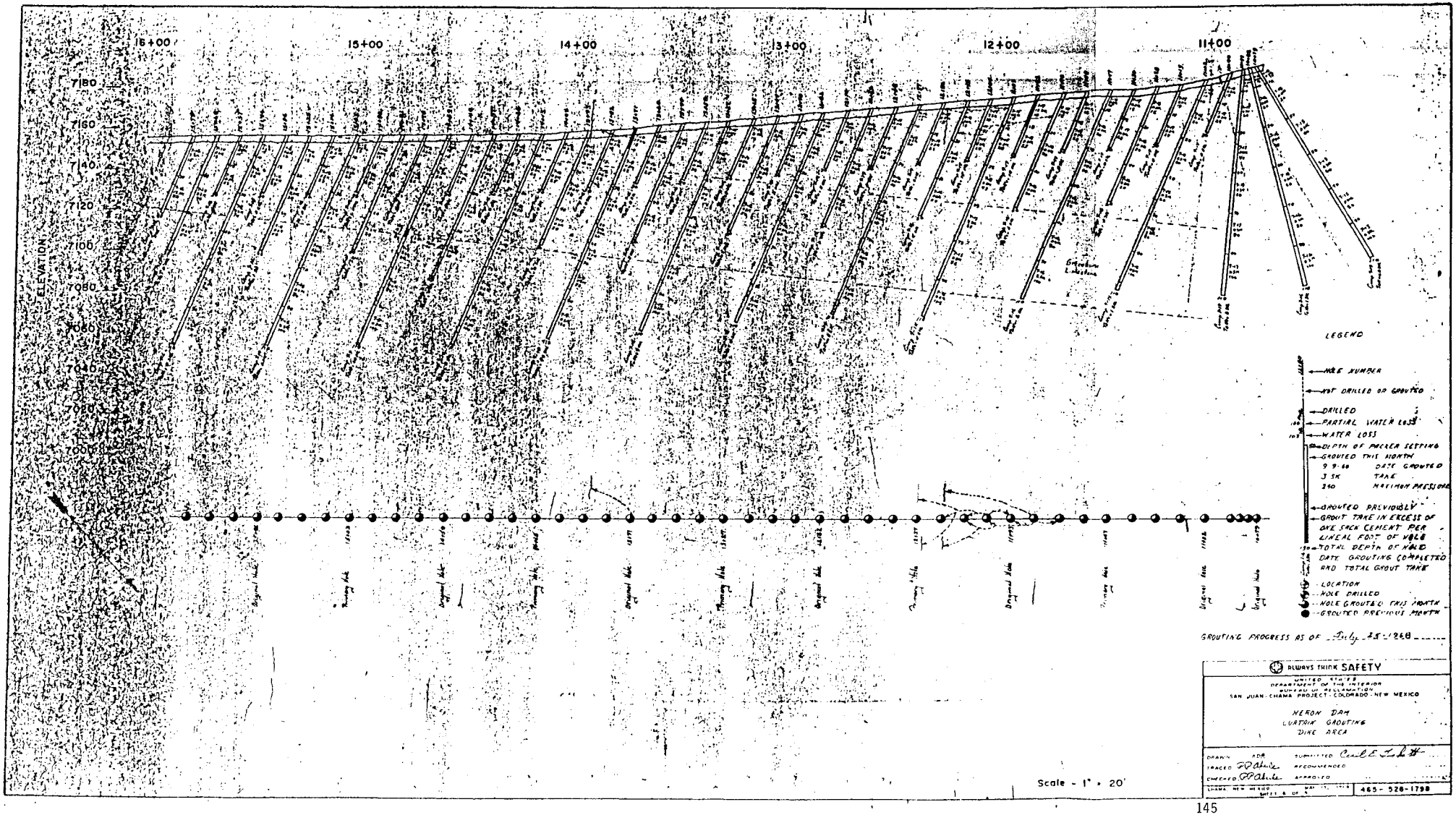
CHAMA, NEW MEXICO MAY 24, 1968 465-528-1796

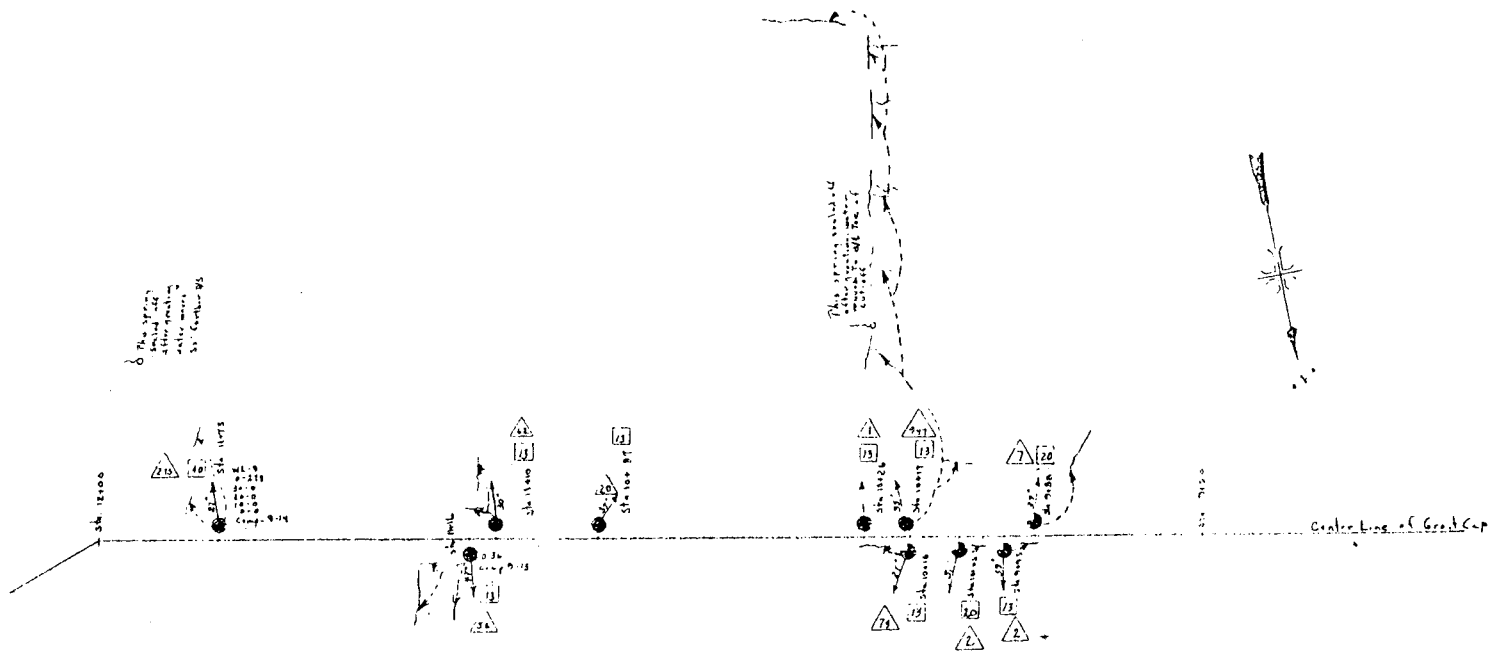

Concrete grout cap
Original ground surface
PROFILE VIEW
PLAN VIEW
EXPLANATION
HOLE NUMBER
NOT DRILLED OR GROUTED
DRILLED
PARTIAL WATER LOSS
WATER LOSS
DEPTH OF PACKER SETTING
GROUTED THIS MONTH
GROUTED PREVIOUSLY
GROUT TAKE IN EXCESS OF ONE SACK PER LINEAL FOOT OF HOLE
DEPTH
DATE GROUTING COMPLETED AND TOTAL GROUT TAKE
SCALE
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN-CHAMA PROJECT - COLORADO - NEW MEXICO
HERON DAM
GROUTING
DIKE AREA
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
465-528-1787
Scale - 1" = 20'


30
29
28
27
26
25
ELEVATION
7200
7180
7160
7140
7120
7100
7080
7060
7040
7020
7000
30+40
25+60
Original ground surface
Concrete grout cap
EXPLANATION
HOLE NUMBER
NOT DRILLED OR GROUTED
DRILLED
PARTIAL WATER LOSS
WATER LOSS
DEPTH OF PACKER SETTING
GROUTED THIS MONTH
9-9-68 --- DATE GROUTED
3 SK --- TAKE
240 ----- MAXIMUM PRESSURE
GROUTED PREVIOUSLY
GROUT TAKE IN EXCESS OF ONE SACK CEMENT PER LINEAL FOOT OF HOLE
TOTAL DEPTH OF HOLE
DATE GROUTING COMPLETED AND TOTAL GROUT TAKE
GROUTING PROGRESS AS OF
Scale - 1" = 20'
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN CHAMA PROJECT - COLORADO NEW MEXICO
DRAWN ADR
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
CHAMA, NEW MEXICO
APRIL 23, 1968
465-528-1801


25+00
24+00
23+00
22+00
21+00
EXPLANATION
HOLE NUMBER
NOT DRILLED OR GROUTED
DRILLED
PARTIAL WATER LOSS
WATER LOSS
DEPTH OF PACKER SETTING
GROUTED THIS MONTH
9-9-68 --- DATE GROUTED
3 SK ----- TAKE
240 ------ MAXIMUM PRESSURE
GROUTED PREVIOUSLY
GROUT TAKE IN EXCESS OF ONE SACK CEMENT PER LINEAL FOOT OF HOLE
110 TOTAL DEPTH OF HOLE
DATE GROUTING COMPLETED AND TOTAL GROUT TAKE
---LOCATION
---HOLE DRILLED
---HOLE GROUTED THIS MONTH
---GROUTED PREVIOUS MONTH
GROUTING PROGRESS AS OF July 25, 1968
Scale - 1" = 20'
RUBAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN - CHAMA PROJECT - COLORADO - NEW MEXICO
NERDY DAM
CURTAIN GROUTING
DIKE AREA
DRAWN
TRACED
CHECKED
ADH
SUBMITTED
RECOMMENDED
APPROVED
CHAMA, NEW MEXICO
MAY 13, 1968
SHEET 3 OF 8
455-528-1802


20+00
19+00
18+00
17+00
16+00
7160
7140
7120
7100
7080
7060
7040
7020
7000
LEGEND
HOLE NUMBER
NOT DRILLED OR GROUTED
DRILLED
PARTIAL WATER LOSS
WATER LOSS
DEPTH OF PACKER SETTING
GROUTED THIS MONTH
9-9-68 — DATE GROUTED
3 SK — TAKE
240 — MAXIMUM PRESSURE
GROUTED PREVIOUSLY
GROUT TAKE IN EXCESS OF ONE SACK CEMENT PER LINEAL FOOT OF HOLE
TOTAL DEPTH OF HOLE
DATE GROUTING COMPLETED AND TOTAL GROUT TAKE
LOCATION
HOLE DRILLED
HOLE GROUTED THIS MONTH
GROUTED PREVIOUS MONTH
GROUTING PROGRESS AS OF July 25-68
Scale - 1" = 20'
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN-CHAMA PROJECT - COLORADO - NEW MEXICO
NEROX DAM
CURTAIN GROUTING
DIKE AREA
DRAWN ADR
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
CHAMA, NEW MEXICO
SHEET 4 OF 4
MAY 11, 1966
463-528-1799


16+00
15+00
14+00
13+00
12+00
11+00
ELEVATION
7180
7160
7140
7120
7100
7080
7060
7040
7020
7000
LEGEND
HOLE NUMBER
NOT DRILLED OR GROUTED
DRILLED
PARTIAL WATER LOSS
WATER LOSS
DEPTH OF PACKER SETTING
GROUTED THIS MONTH
9-9-60 DATE GROUTED
3 SK TAKE
240 MAXIMUM PRESSURE
GROUTED PREVIOUSLY
GROUT TAKE IN EXCESS OF ONE SACK CEMENT PER LINEAL FOOT OF HOLE
TOTAL DEPTH OF HOLE
DATE GROUTING COMPLETED AND TOTAL GROUT TAKE
LOCATION
HOLE DRILLED
HOLE GROUTED THIS MONTH
GROUTED PREVIOUS MONTH
GROUTING PROGRESS AS OF July 25, 1960
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN-CHAMA PROJECT, COLORADO-NEW MEXICO
HERON DAM
LURTON GROUTING
DIKE AREA
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
CHAMA, NEW MEXICO
SHEET 8 OF 8
465-526-1798
Scale - 1" = 20'



GROUTING PROGRESS AS OF Oct. 26-69

LEGEND
BLANKET GROUTING

- Depth of hole
- Take in sacks
- Grout Travel
- Direction of hole and angle of pipe from vertical

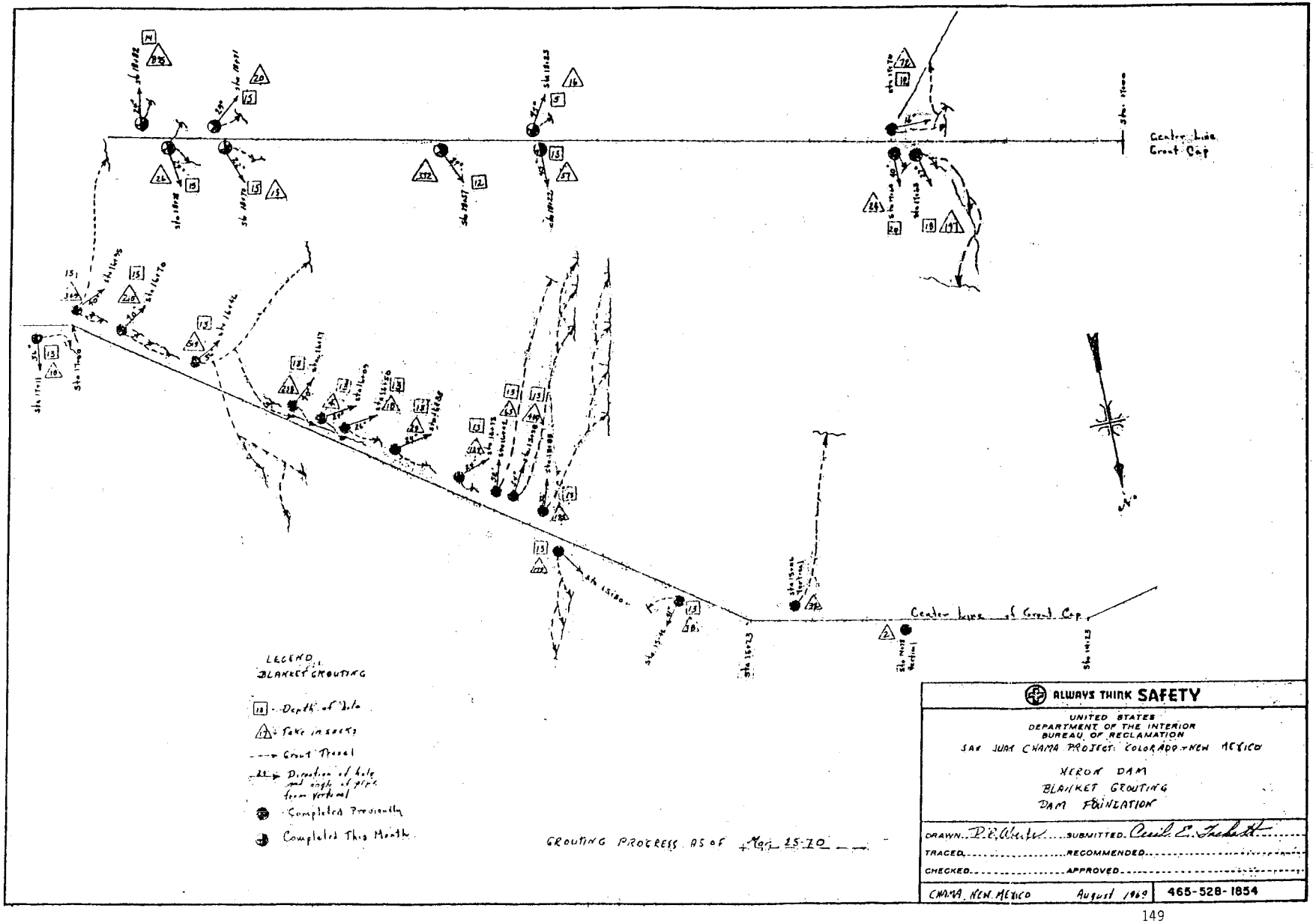
ALWAYS THINK SAFETY

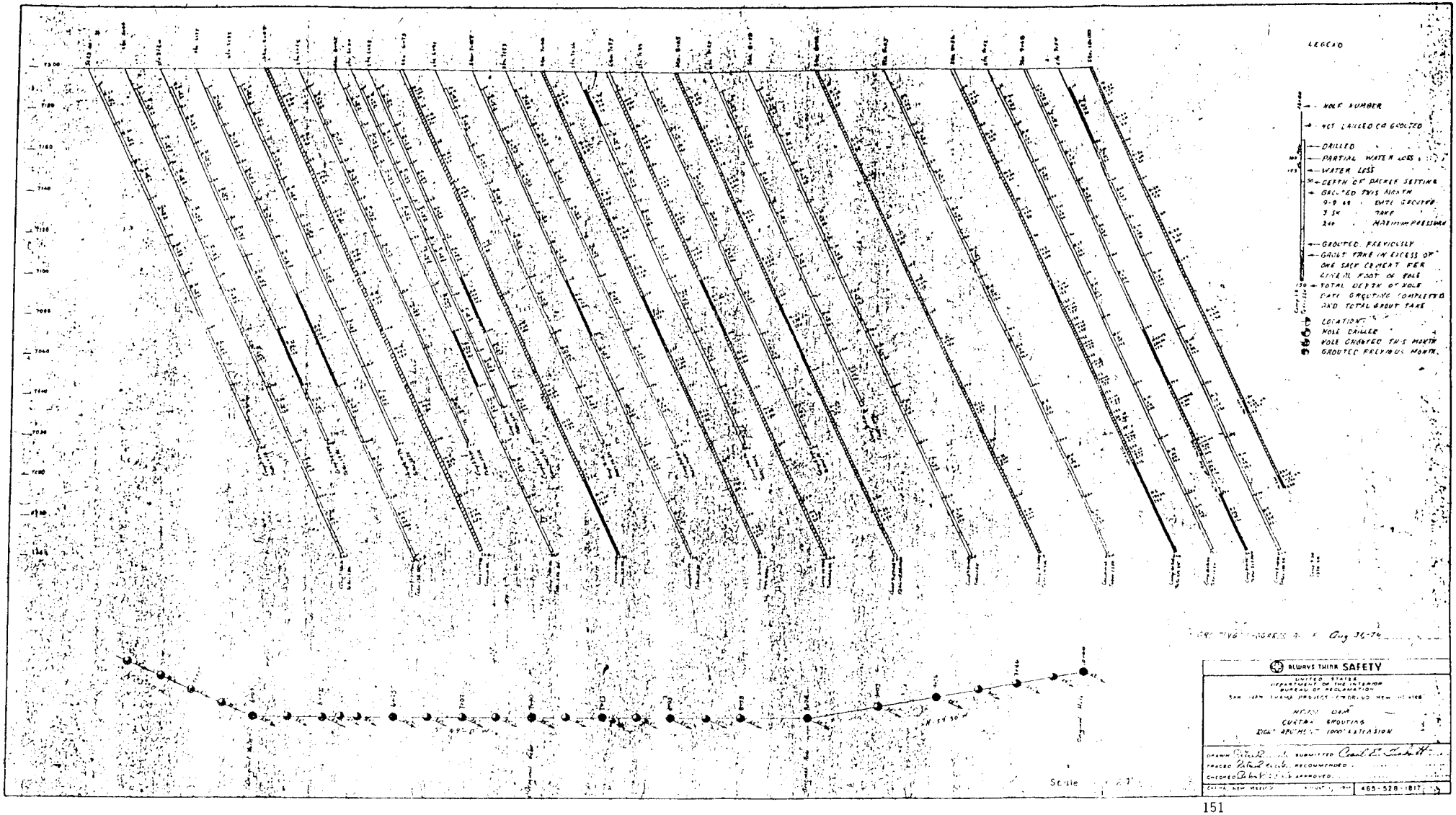
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN CHAMA PROJECT COLORADO-NEW MEXICO

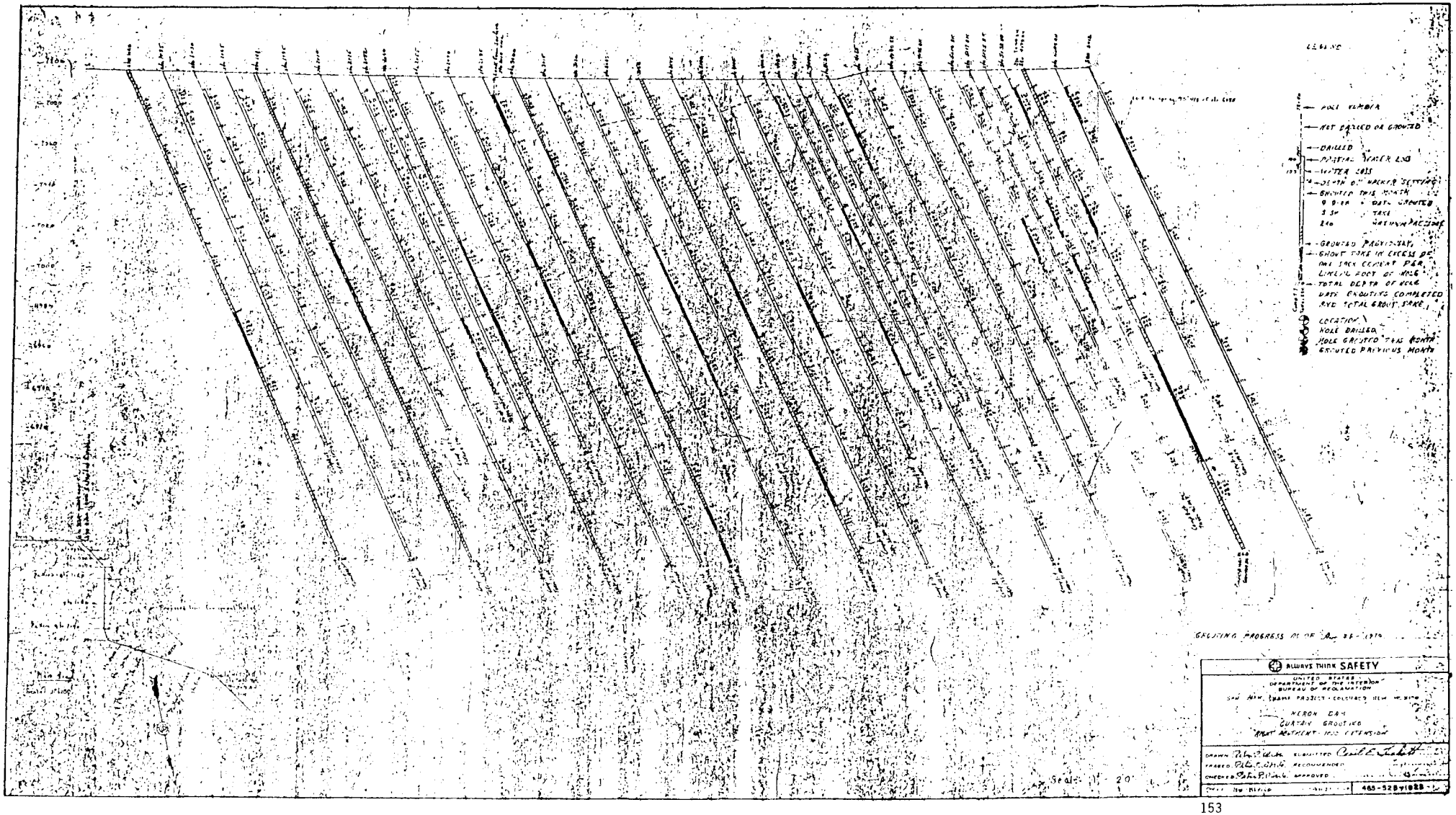
NEKON DAM
BLANKET GROUTING
DAM FOUNDATION

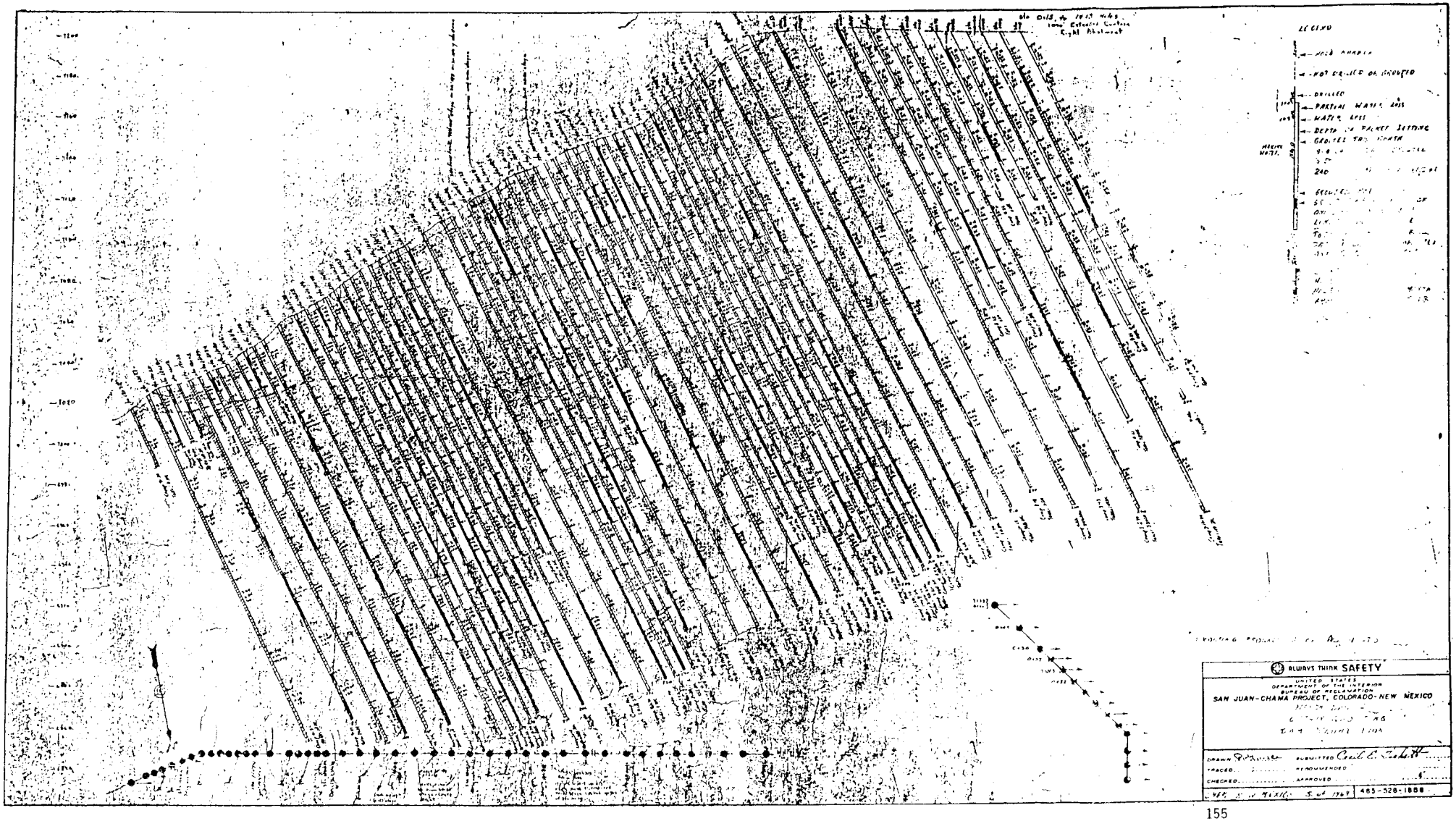
DRAWN [illegible] SUBMITTED [illegible]
TRACED RECOMMENDED
CHECKED APPROVED

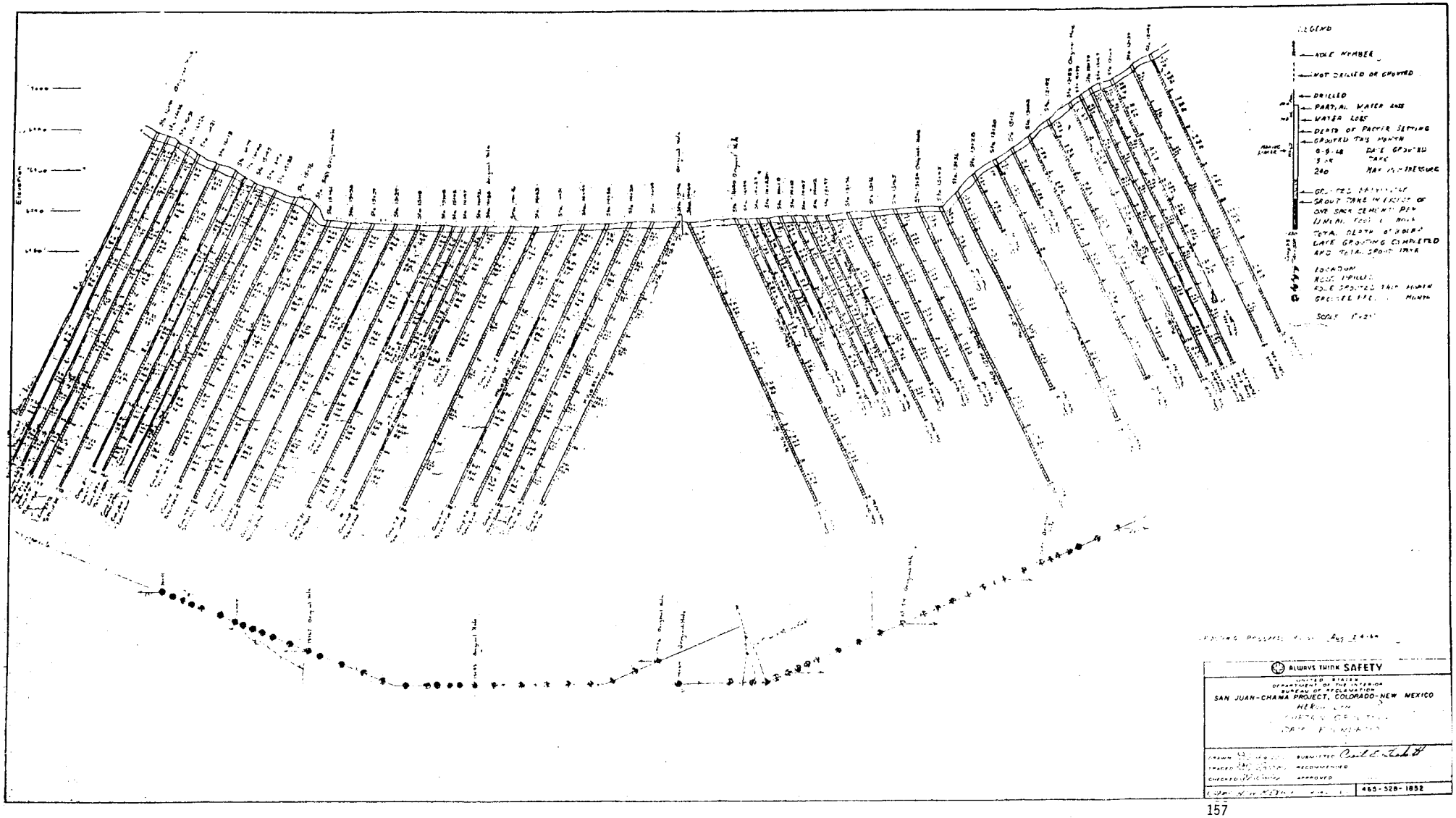
CHAMA NEW MEXICO Sept. 1959 | 465-528-1855

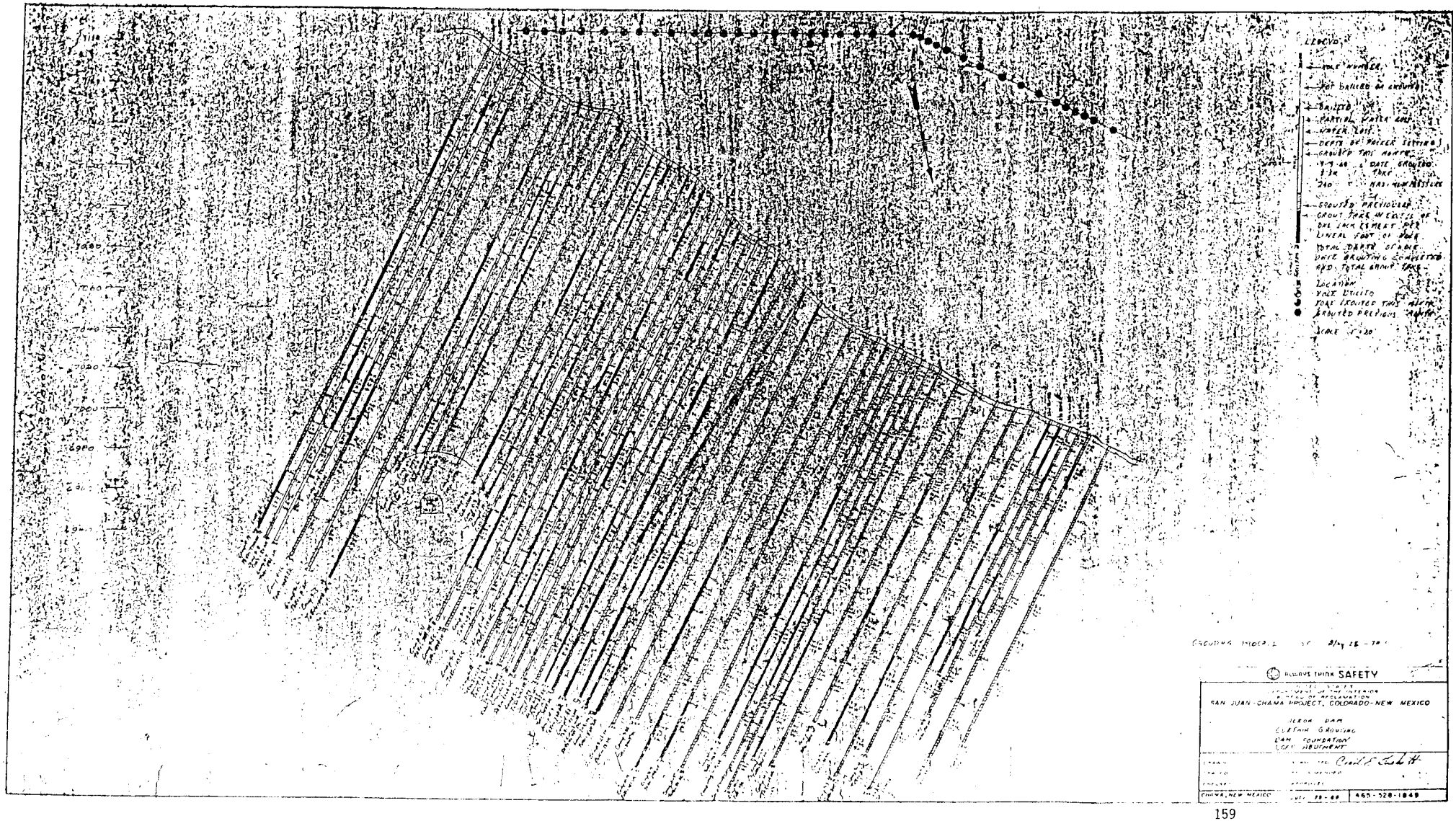

Center Line Grout Cap
Center Line of Grout Cap
LEGEND
BLANKET GROUTING
Depth of hole
Take in sacks
Grout Travel
Direction of hole and angle of pipe from vertical
Completed Previously
Completed This Month
GROUTING PROGRESS AS OF May 25-70
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN CHAMA PROJECT COLORADO-NEW MEXICO
NEROX DAM
BLANKET GROUTING
DAM FOUNDATION
DRAWN
SUBMITTED
TRACED
RECOMMENDED
CHECKED
APPROVED
CHAMA, NEW MEXICO
August 1969
465-528-1854

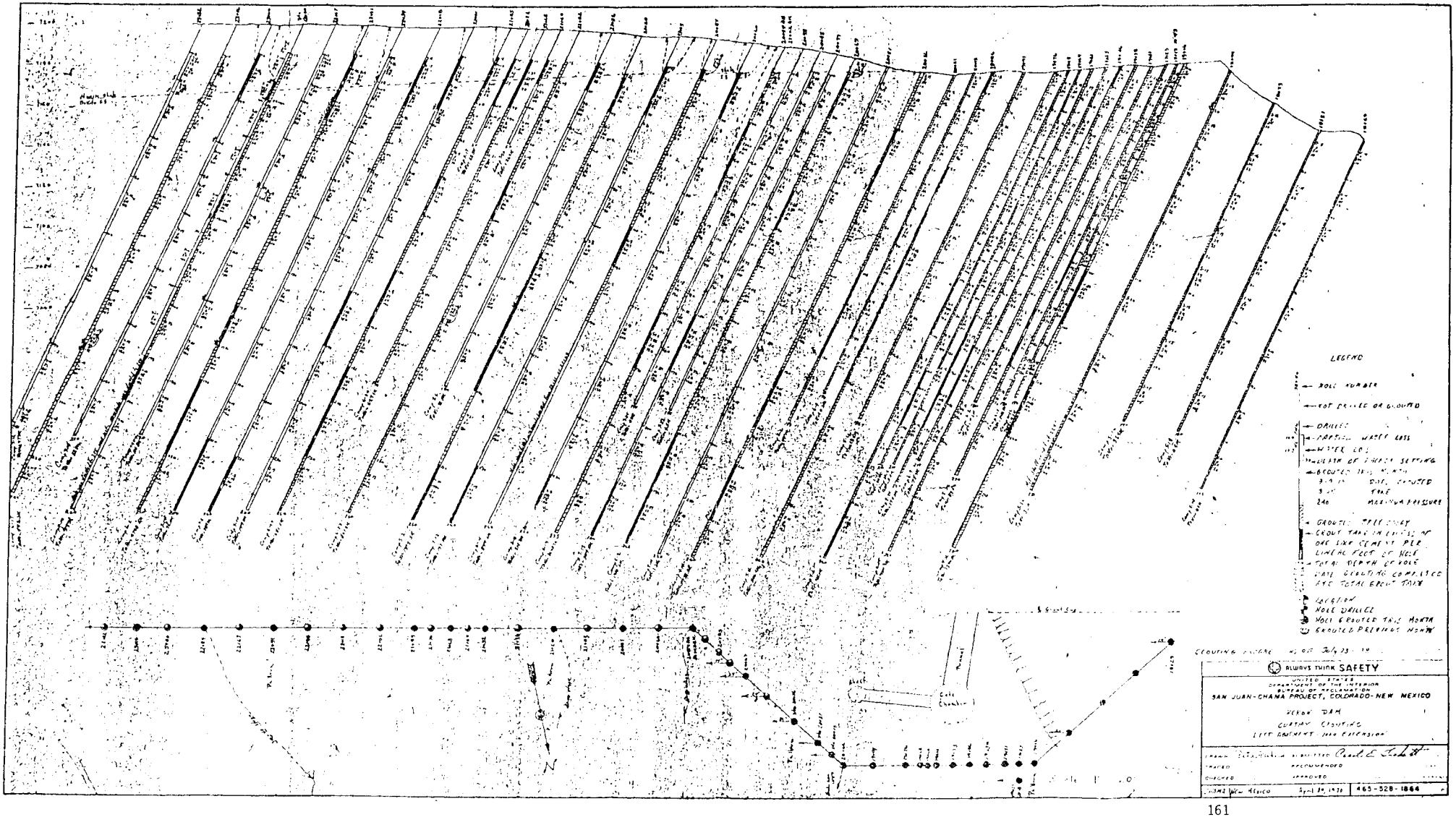

LEGEND
HOLE NUMBER
NOT DRILLED OR GROUTED
DRILLED
PARTIAL WATER LOSS
WATER LOSS
DEPTH OF PACKER SETTING
GROUTED THIS MONTH
DATE GROUTED
TAKE
MAXIMUM PRESSURE
GROUTED PREVIOUSLY
GROUT TAKE IN EXCESS OF ONE SACK CEMENT PER LINEAL FOOT OF HOLE
TOTAL DEPTH OF HOLE
DATE GROUTING COMPLETED AND TOTAL GROUT TAKE
LOCATIONS
HOLE DRILLED
HOLE GROUTED THIS MONTH
GROUTED PREVIOUS MONTH
Aug 30-74
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
DAM
CURTAIN GROUTING
RIGHT ABUTMENT 1000' EXTENSION
SUBMITTED
RECOMMENDED
APPROVED
465-528-1817
Scale

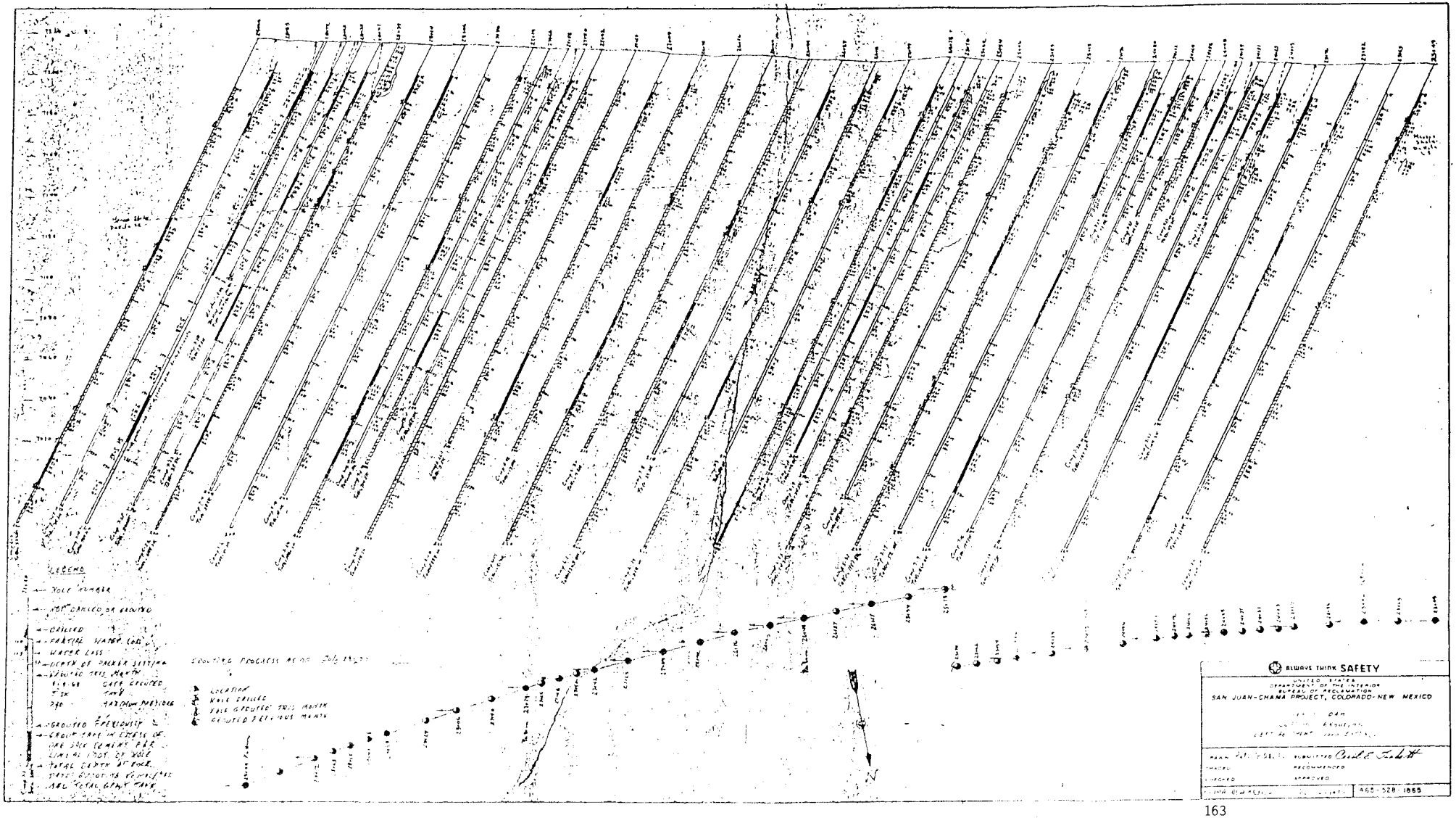

HOLE NUMBER
NOT DRILLED OR GROUTED
DRILLED
PARTIAL WATER LOSS
WATER LOSS
DEPTH OF PACKER SETTING
GROUTED THIS MONTH
DATE GROUTED
TAKE
MAXIMUM PRESSURE
GROUTED PREVIOUSLY
GROUT TAKE IN EXCESS OF ONE SACK CEMENT PER LINEAL FOOT OF HOLE
TOTAL DEPTH OF HOLE
DATE GROUTING COMPLETED
AVE TOTAL GROUT TAKE
LOCATION
HOLE DRILLED
HOLE GROUTED THIS MONTH
GROUTED PREVIOUS MONTH
GROUTING PROGRESS AS OF
Scale: 1" = 20'
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN MIGUEL PROJECT - COLORADO
NEW MEXICO
NERON DAM
CURTAIN GROUTING
RIGHT ABUTMENT - INCL EXTENSION
DRAWN
SUBMITTED
TRACED
RECOMMENDED
CHECKED
APPROVED
465-528V1028

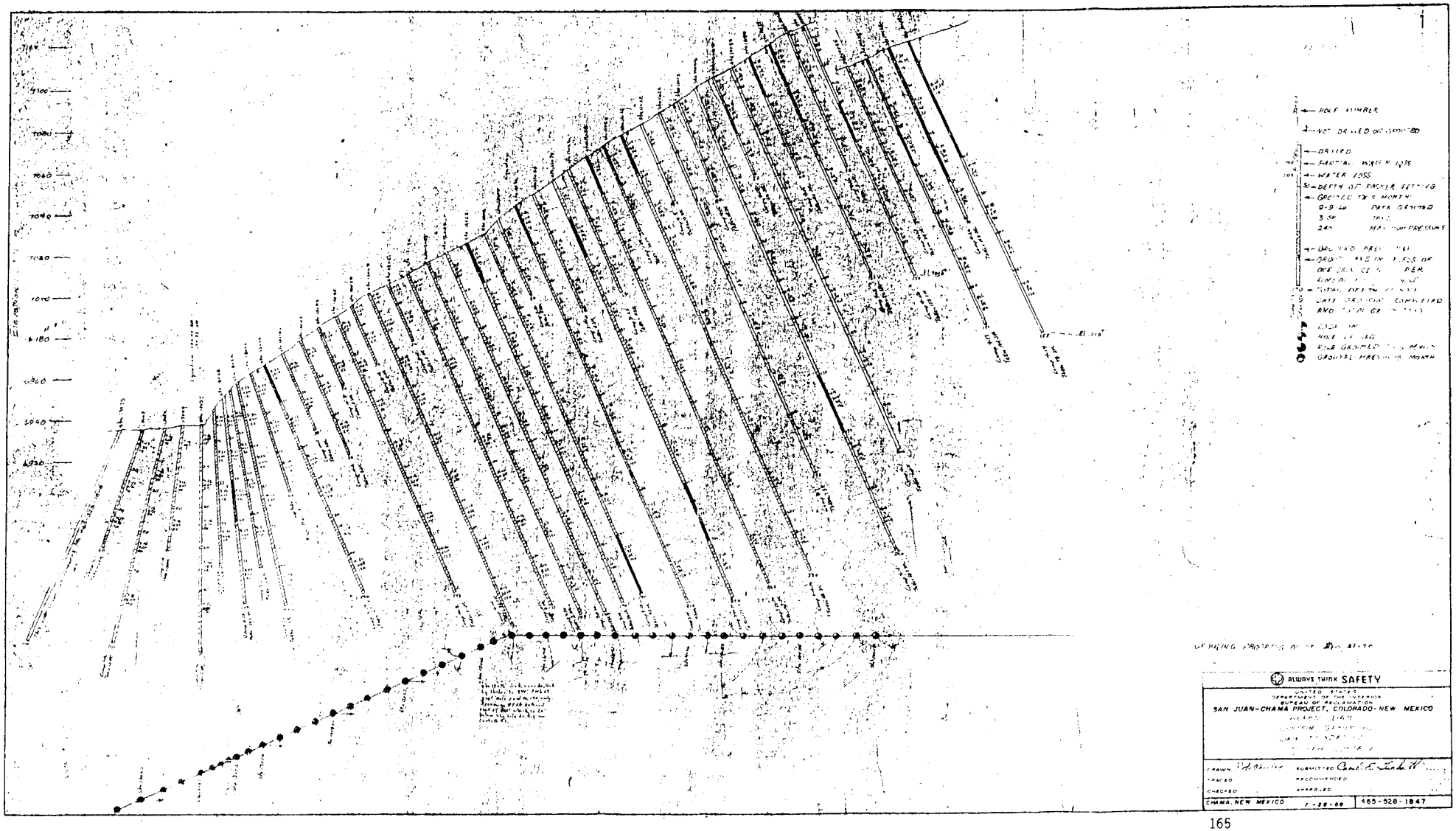

LEGEND
DRILLED
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN-CHAMA PROJECT, COLORADO-NEW MEXICO
DRAWN
SUBMITTED
TRACED
RECOMMENDED
CHECKED
APPROVED
465-528-1888

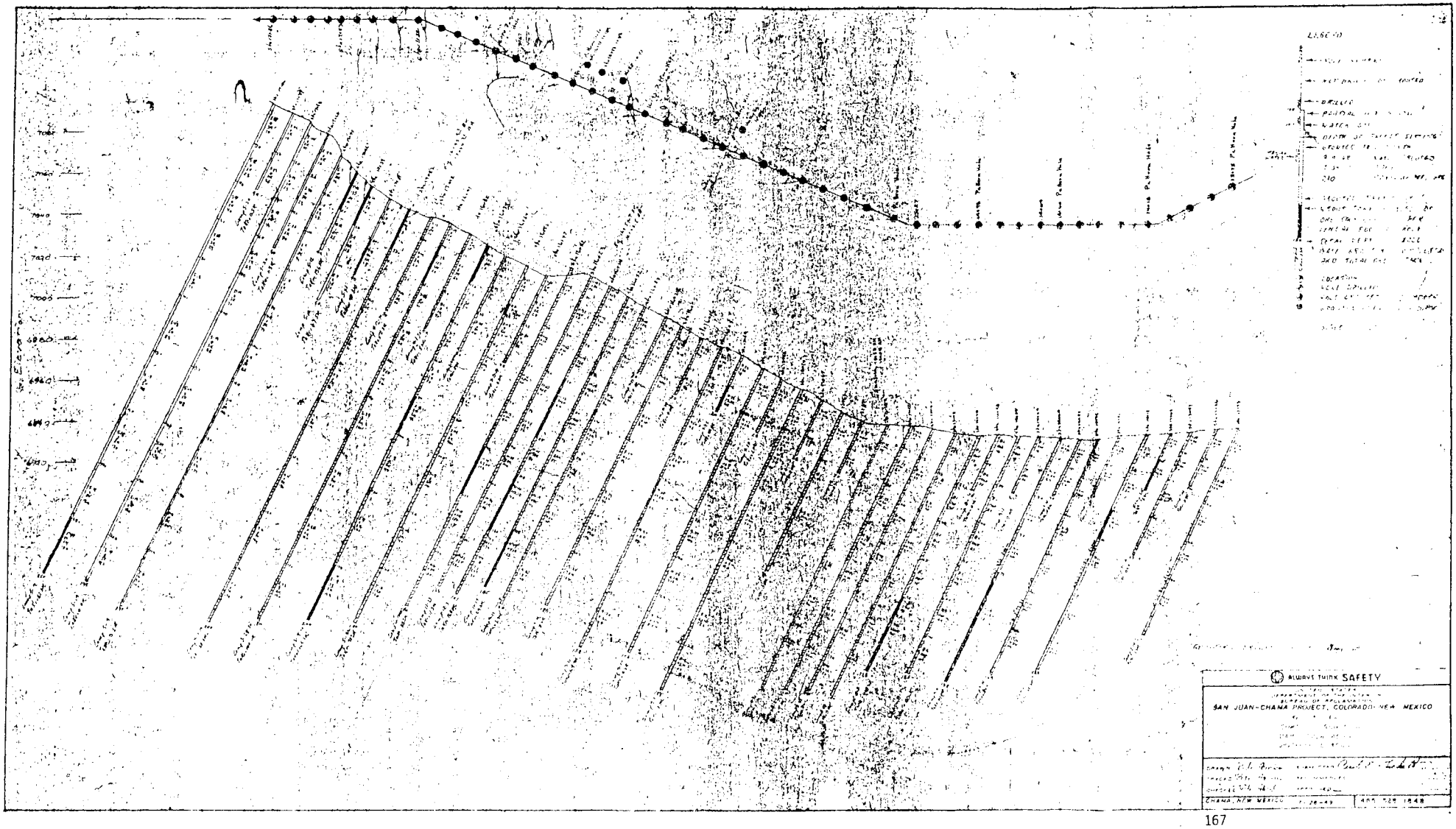

LEGEND
HOLE NUMBER
NOT DRILLED OR GROUTED
DRILLED
PARTIAL WATER LOSS
WATER LOSS
DEPTH OF PACKER SETTING
GROUTED THIS MONTH
DATE GROUTED
TOTAL DEPTH OF HOLE
DATE GROUTING COMPLETED
AND TOTAL GROUT TAKE
LOCATION
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN-CHAMA PROJECT, COLORADO-NEW MEXICO
465-528-1852

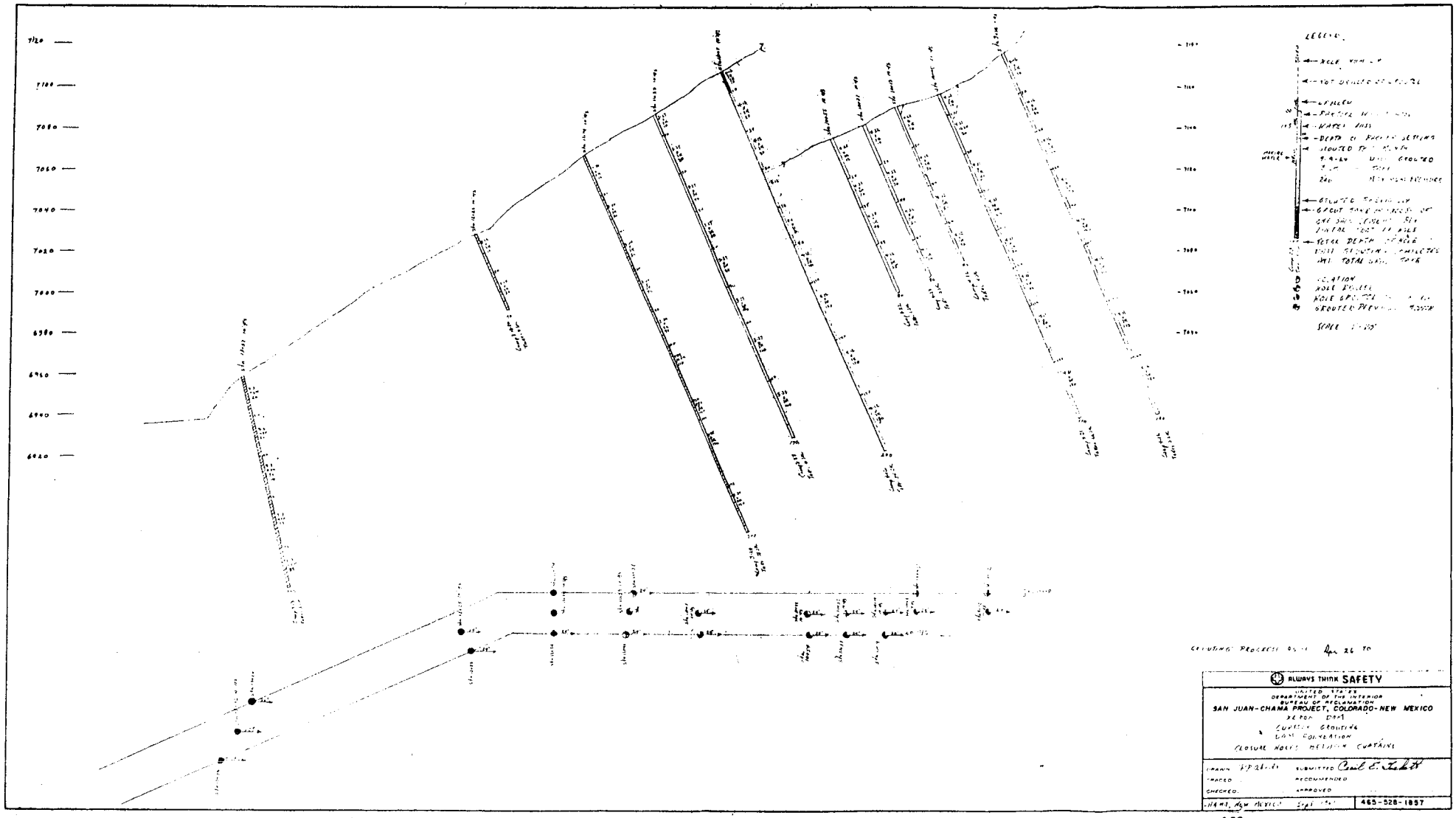

ALWAYS THINK SAFETY
SAN JUAN-CHAMA PROJECT, COLORADO-NEW MEXICO
CHAMA, NEW MEXICO
465-528-1849

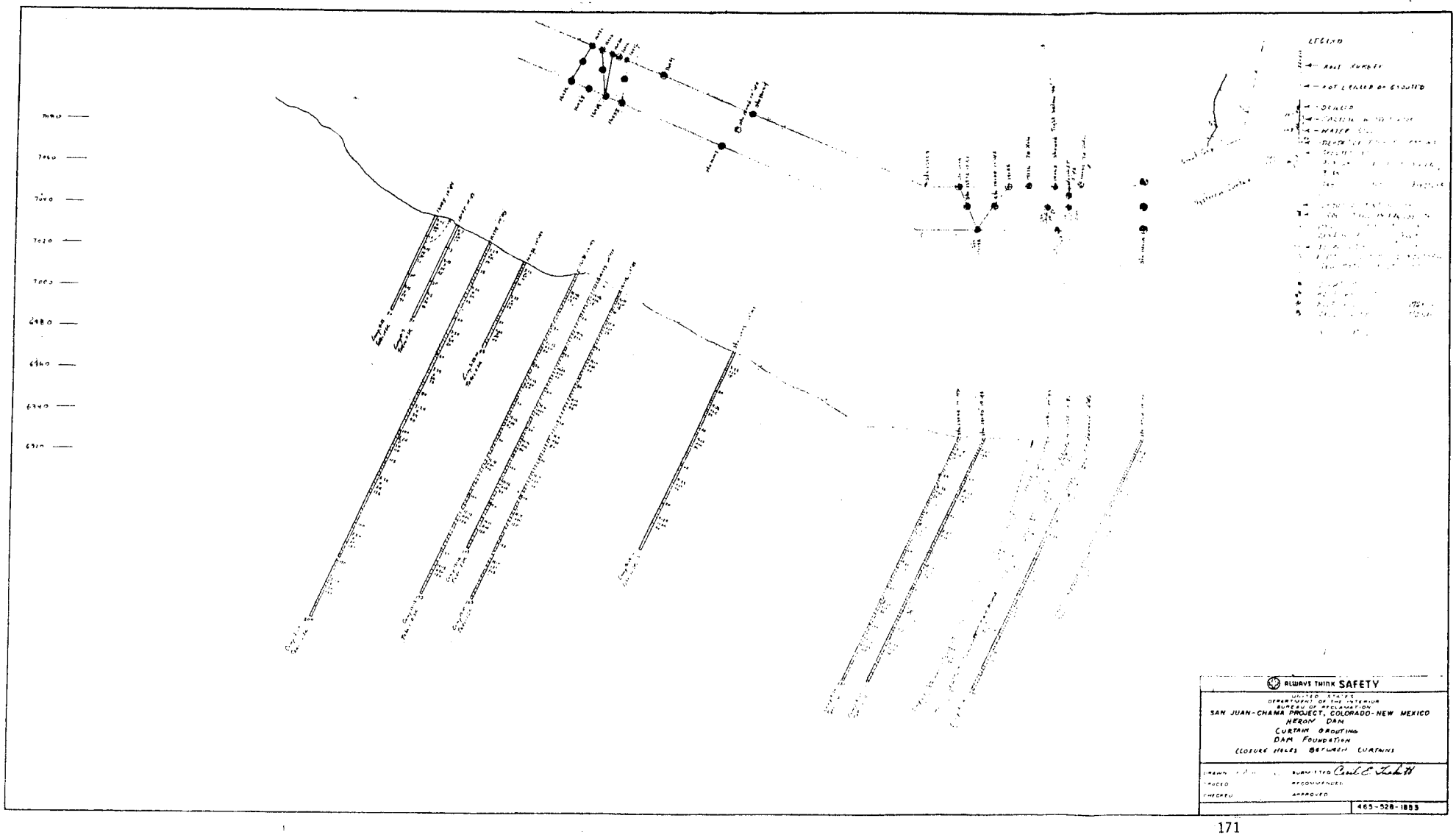

LEGEND
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN-CHAMA PROJECT, COLORADO-NEW MEXICO
VERDE DAM
CURTAIN GROUTING
LEFT ABUTMENT - MAIN EXTENSION
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
DENVER, NEW MEXICO
April 24, 1970
465-528-1864

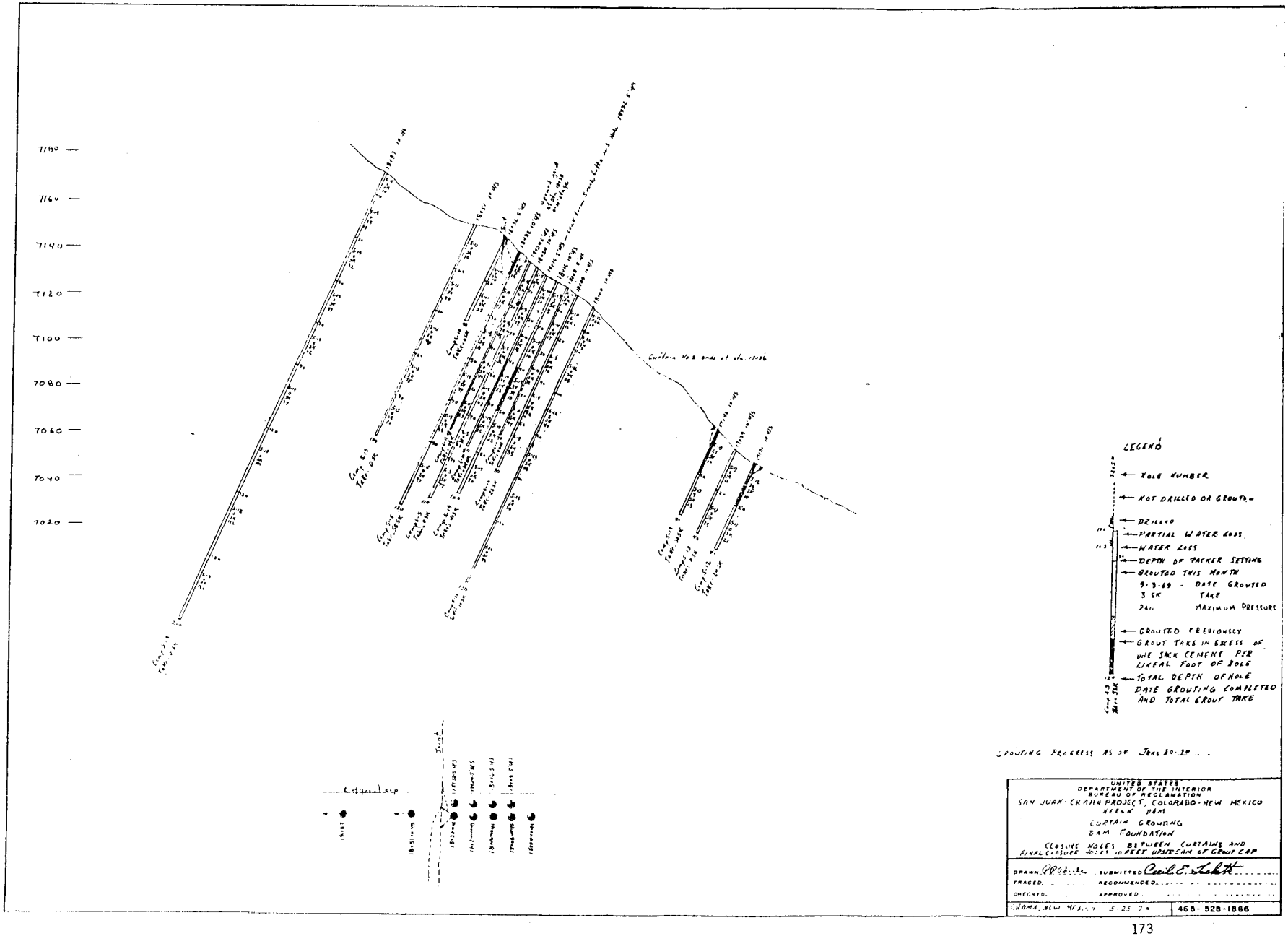

LEGEND
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN-CHAMA PROJECT, COLORADO-NEW MEXICO
DAM
RECOMMENDED
APPROVED
465-528-1865


HOLE NUMBER
DRILLED
PARTIAL WATER LOSS
WATER LOSS
DEPTH OF PACKER SETTING
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN-CHAMA PROJECT, COLORADO-NEW MEXICO
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
CHAMA, NEW MEXICO
465-528-1847


ALWAYS THINK SAFETY
SAN JUAN-CHAMA PROJECT, COLORADO-NEW MEXICO


7120
7100
7080
7060
7040
7020
7000
6980
6960
6940
6920
LEGEND
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN-CHAMA PROJECT, COLORADO-NEW MEXICO
CURTAIN GROUTING
DAM FOUNDATION
CLOSURE HOLES BETWEEN CURTAINS
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
465-528-1857


ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN-CHAMA PROJECT, COLORADO-NEW MEXICO
HERON DAM
CURTAIN GROUTING
DAM FOUNDATION
CLOSURE HOLES BETWEEN CURTAINS
465-528-1883


7160
7140
7120
7100
7080
7060
7040
7020
LEGEND
HOLE NUMBER
NOT DRILLED OR GROUTED
DRILLED
PARTIAL WATER LOSS
WATER LOSS
DEPTH OF PACKER SETTING
GROUTED THIS MONTH
9-3-69 - DATE GROUTED
3 SK TAKE
240 MAXIMUM PRESSURE
GROUTED PREVIOUSLY
GROUT TAKE IN EXCESS OF ONE SACK CEMENT PER LINEAL FOOT OF HOLE
TOTAL DEPTH OF HOLE
DATE GROUTING COMPLETED AND TOTAL GROUT TAKE
GROUTING PROGRESS AS OF JULY 30-29
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN-CHAMA PROJECT, COLORADO-NEW MEXICO
NAVAJO DAM
CURTAIN GROUTING
DAM FOUNDATION
CLOSURE HOLES BETWEEN CURTAINS AND FINAL CLOSURE HOLES 10 FEET UPSTREAM OF GROUT CAP
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
CHAMA, NEW MEXICO 5-25-70
465-528-1866

APPENDIX B

Extract from "Final Construction Geology Report of Heron Dam" prepared by Kenneth R. Cooper, Project Geologist October 1970.

Grout Takes in Relation to Geology

Many grout takes in abutments at Heron Dam were related to steeply dipping to vertical joints striking NS and parallel to steep slopes of Willow Creek Canyon. These joints originated from stress release resulting from down-cutting of Willow Creek Canyon. Most grout takes were accompanied by high back pressures indicative of vertical joints.

On grouting a hole at Station 3+00 on the 1000 foot extension of the grout curtain in the right abutment, grout leaks occurred on the surface from 30 feet south of the hole to 300 feet north of the hole along a north - south line. Grout take including leakage was reported at 1681 sacks of cement in this hole. A near-vertical stress relief joint striking north - south was concluded responsible for this grout take, grout leak and distance of travel. Surface trace of this joint was not evident.

A similar situation was present in the left abutment. While grouting a horizontal hole in the access shaft at elevation 7105 feet, grout leaks occurred along a north - south line from 100 to 600 feet north of the shaft. The grout take in this hole including the leak was reported at 1021 sacks of cement. While grouting another horizontal hole in the access shaft at elevation 7125 feet, grout leaks occurred at the surface along a north - south line from 100 to 230 feet north of the access shaft. Grout take including leakage in this hole was reported at 1956 sacks of cement. Vertical stress relief joints striking north - south and parallel to Willow Creek Canyon were concluded responsible for grout takes and grout leaks in these holes. The grout leaks on the surface from the two horizontal holes drilled in the access shaft could only be through vertical fractures or stress relief joints striking north - south and parallel to Willow Creek Canyon. These joints or fractures are unrelated to doming, but originated from stress relief resulting from downcutting of Willow Creek Canyon. Surface traces of these joints were not evident.

Bedding planes may have been responsible for some grout leaks, grout takes and grout travel. Grout leaks occurred 430 feet downstream from the grout cap on the left abutment along a shale unit in the Dakota formation. A grout leak related to the same shale unit occurred 600 feet downstream from the grout cap above the outlet portal. Although these leaks were related to a particular shale unit, grout travel could not be attributed solely to bedding or to the shale unit. The interval being grouted was 50 to 70 feet below the shale unit and vertical travel of grout could only be up through jointing. In a few places grout travel occurred between adjacent holes and was indicative of grout movement along bedding planes.

Grout takes were also related to jointing in the sandstone units in the Dakota formation. These joint sets are connected with uparching in the North El Vado Dome and not to stress release related to downcutting of Chama and Willow Canyons. A grout take of 4,136 sacks of cement was obtained in the interval 210 to 240 feet in the hole drilled at Station 20+36 on the left abutment with no grout leaks. A grout leak did occur in the access shaft 100 feet above the grout take. A grout take of 1131 sacks of cement was obtained in the 200 to 230 foot interval in the hole drilled at Station 10+00 with no grout leaks. Many other examples of grout takes, but of smaller volume, occurred with no grout leaks. Grout similar to mortar in a brick wall was observed filling joints in a few beds of sandstone exposed by cleanup of the abutments.

It is visualized that during uparching of North El Vado Dome, the sandstone units deformed principally by fracturing with the development of jointing while the shale units deformed principally by plastic flow. Consequently, joints in the sandstone did not continue through, but ended at beds of shale. With development of Chama River and Willow Creek canyons, these joints opened from stress relief and resulted in a network of open joints in sandstone units between relatively tight shale units. This condition, in combination with stress relief jointing parallel to steep slopes of Willow Canyon is concluded responsible for most of the grout take.

Grout takes and grout leaks in the right abutment in vicinity of Station 10+86 are apparently related to shear zones mapped in this area (see Drawing No. 465-528-1874). Rock in this vicinity was closely jointed and fractured. Grout leaks occurred at several of the shears.

Grout takes in the foundation area were much smaller than in abutments. The apparent random occurrance of grout takes and absence of connection between grout holes indicated joints in the Morrison formation rather than bedding planes were primarily responsible for grout takes. The largest grout take in the foundation area was obtained in the hole drilled at Station 14+85 where a take of 518 sacks of cement was reported for the hole. Most holes drilled in the foundation area had grout takes of less than 200 sacks of cement.

Some rock movement occurred while grouting in the left abutment. The grout cap separated at Station 18+38 and several silt and clay filled fractures and joints were opened. Fresh fractures in rock were not found. The convex shape and steep slope of the cutoff trench resulting from excavation of the cutoff trench created unstable conditions in vicinity of Station 18+38. The addition of water and grout under slight pressure was sufficient to open pre-existing silt and clay filled joints fractures and bedding planes in this area. Uplift of 0.13 feet was reported on rock in vicinity of Station 18+38.

Grout takes in the foundation of the dike were much less than in the abutments of the dam. Many holes drilled in this area were tight. Stress relief joints were absent in the foundation of the dike, consequently, the rock was much tighter in this area than in the abutments of the dam.

The largest grout takes in the foundation of the dike occurred at the east end where blasting for excavation of the spillway had opened joints and bedding planes in sandstone.

Relationships of grout holes, grout takes, grout leaks and rock types in abutments and foundation of the dam are illustrated on Drawings No. 465-528-1817, 1849, 1852, 1856 and 1865. Relationships of grout holes, grout takes, grout leaks and rock types in the foundation of the dike are illustrated on Drawings No. 465-528-1797, 1798, 1799, 1801 and 1802.

Conclusion: Jointing in sandstone was primarily responsible for grout takes and grout leaks in abutments and foundation at Heron Dam and Dike. At the dam, joints responsible for grout leaks and greater distance of grout travel resulted from stress relief in steep slopes of Willow Creek Canyon. They were not distinguishable on the surface from other joints present because they were parallel to a pre-existing set of joints.

Reservoir Geology

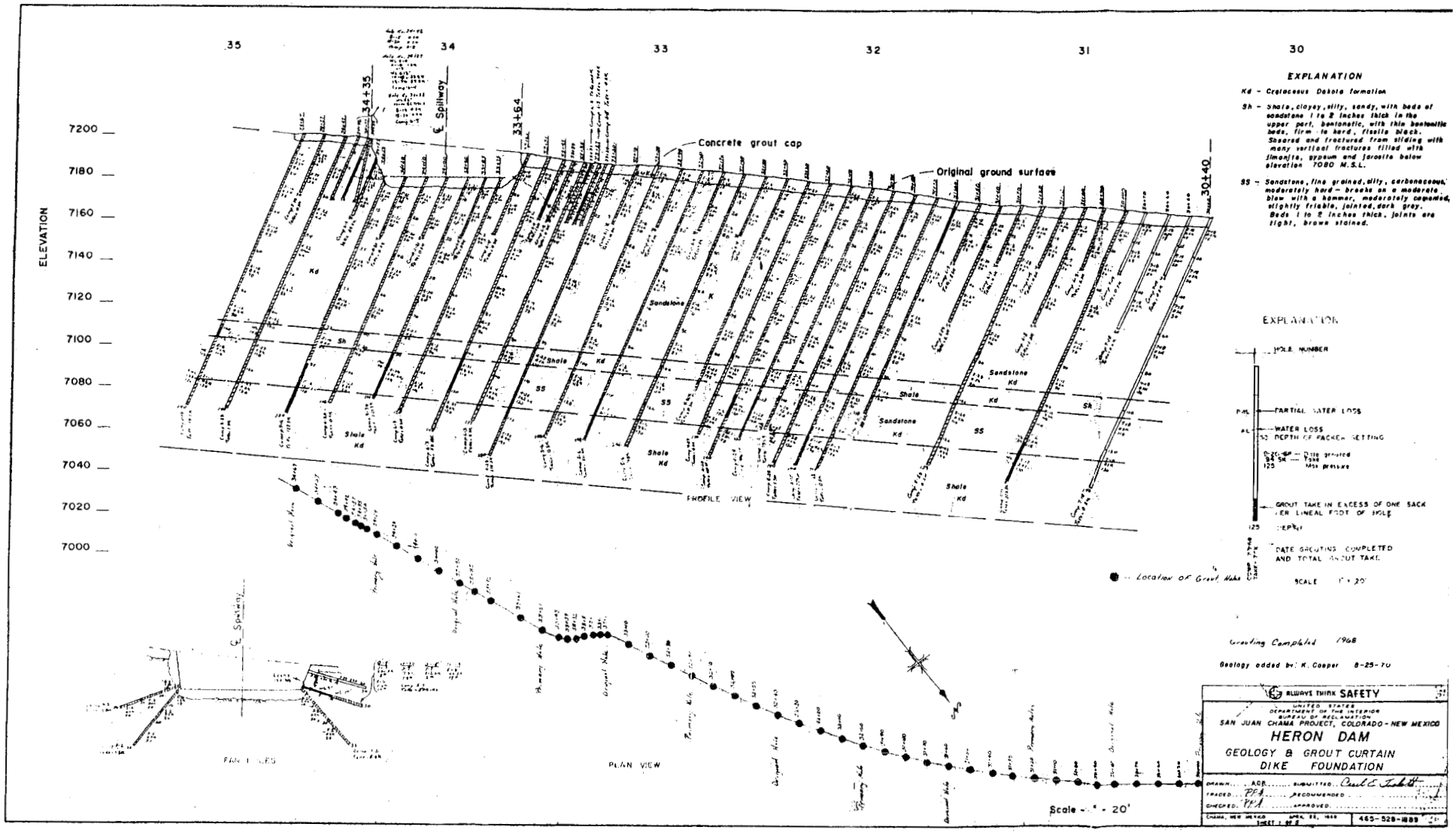
The Dakota formation lies beneath Mancos shale and alluvium in most of the reservoir area. It crops out in the reservoir in vicinity of the dam and in Horse Lake Creek valley near the west edge of the reservoir and in a small area along Willow Creek about 3 miles upstream from the dam. A dip slope at the top of the formation constitutes the outcrop of the Dakota in the reservoir area except along Willow Creek where it forms bluffs on both sides of the canyon at the dam.

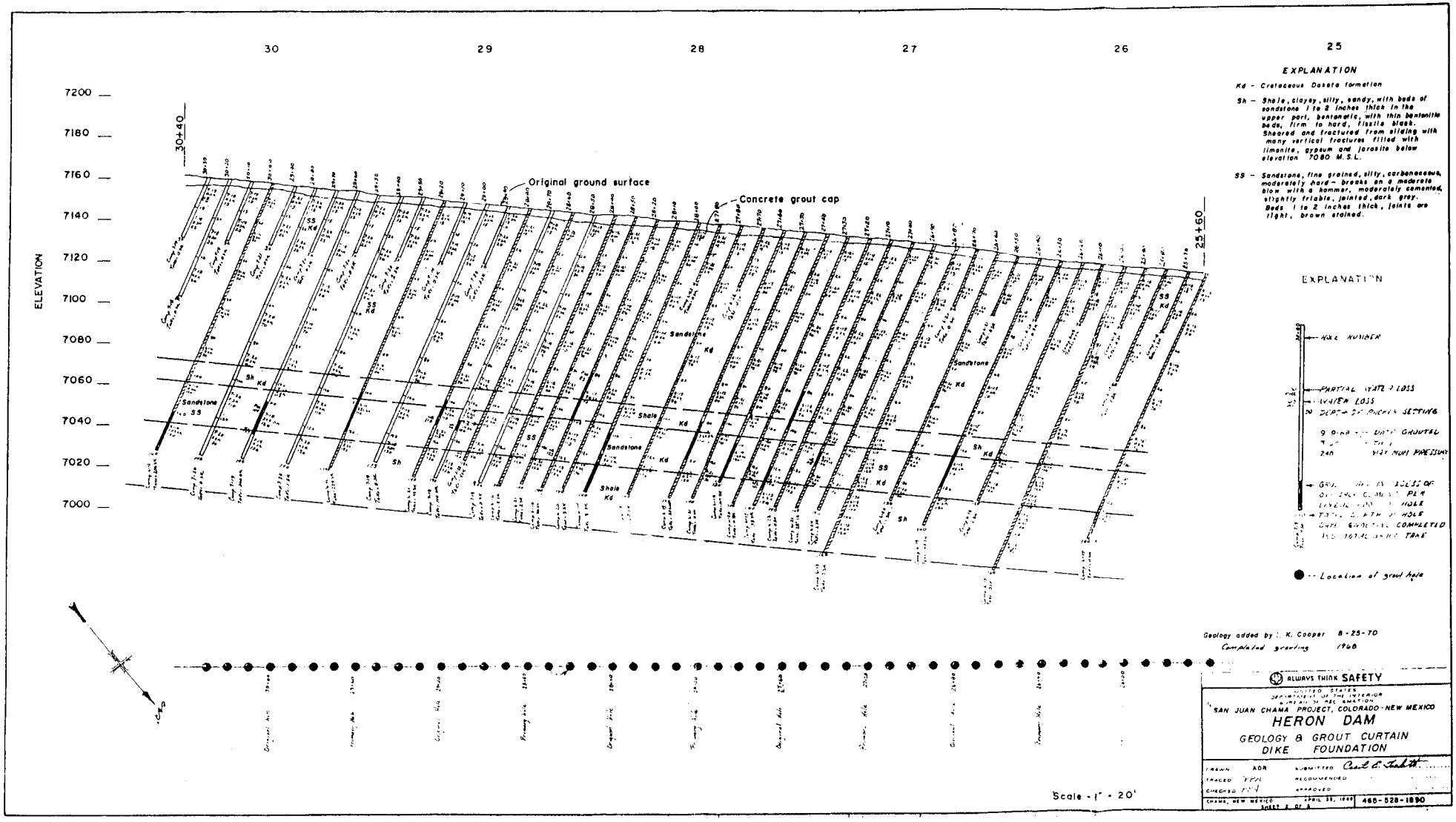
Sandstone at the top of the Dakota is closely jointed on outcrops. The joints appear tight and unhealed. Where Willow Creek has eroded its canyon into the Dakota, the joints are observed to decrease in number with depth below the surface. A few stress relief joints striking parallel to Chama River and Willow Creek canyons are present near the canyon rim and were traced for several hundred feet along their strike. Some of these joints are open from 1 to 12 inches to depths of 10 to 40 feet below the surface.

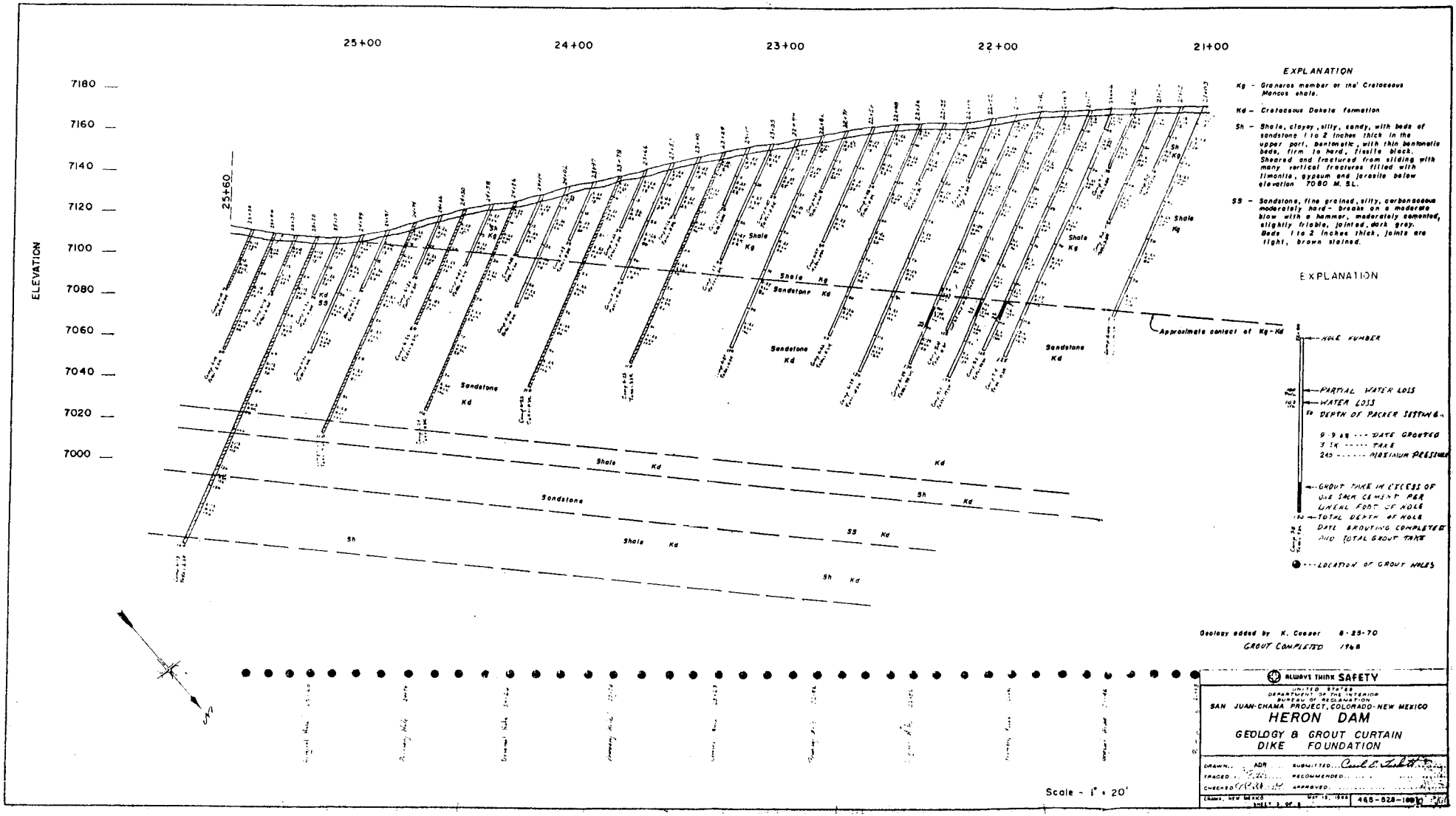
Several faults were observed in the Dakota formation in the reservoir area. Two of these faults are near the dam and are shown on the detailed geologic map of the reservoir are, Drawings No. 465-528-496 and 497. One fault is inferred by an abrupt change in dip on the east side of the Dakota outcrop in Horse Lake Creek valley. Faulting was also observed in the Dakota formation outcropping along Willow Creek in the upstream portion of the reservoir and is shown on the generalized map of the reservoir, Drawing No. 465-528-1881. The fault zones were tight with no openings, eroded channels or springs indicative of water movement along their strike.

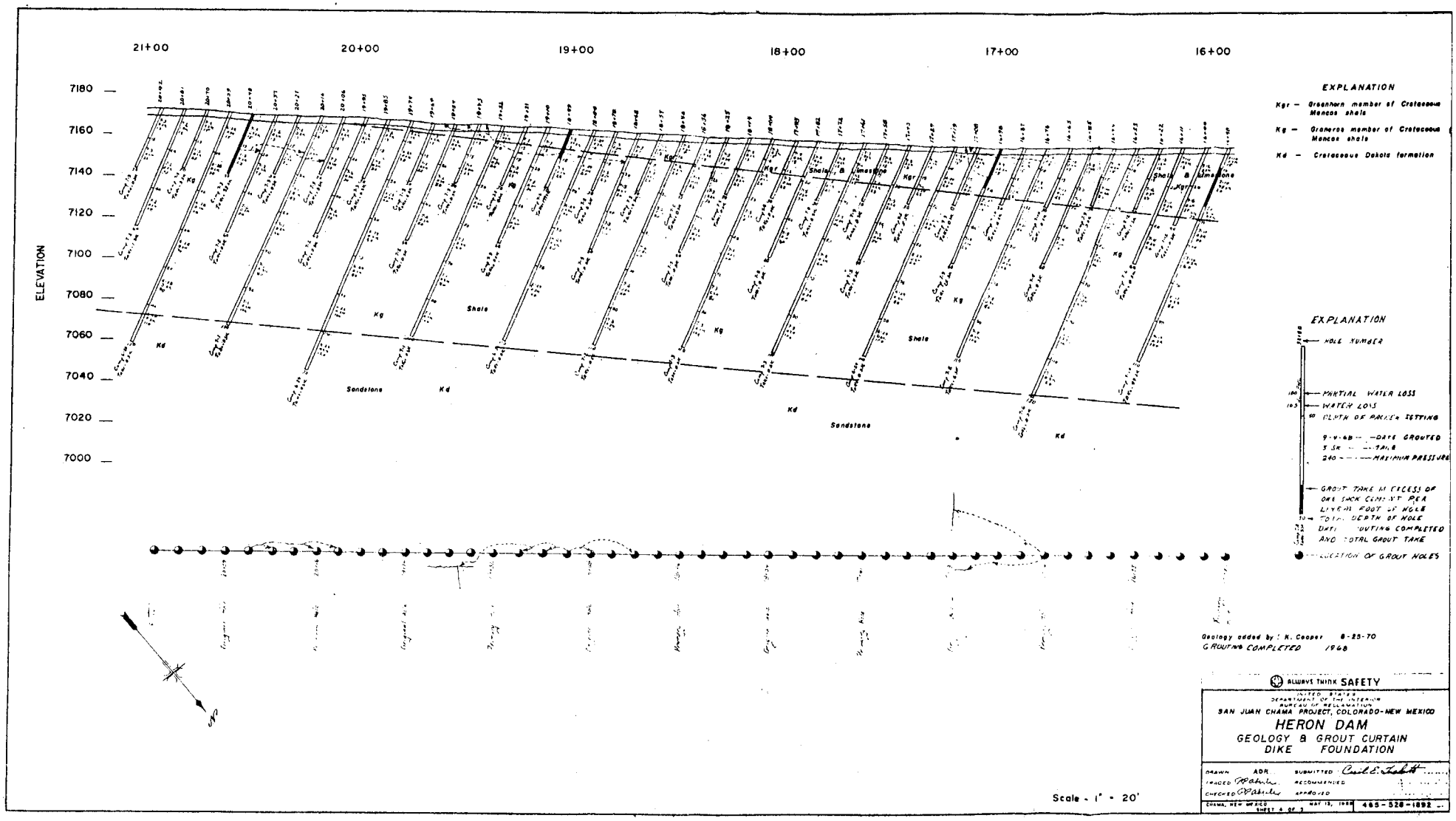
Shale of the Mancos formation underlies most of the reservoir and constitutes the rock in the east rim. The shale is weathered to depths of 1 to 10 feet and in places is covered with several feet of alluvium. Geologic structure at outcrops of the Mancos formation has been obscured by weathering. Jointing was observed in excavations in the Mancos formation, but appeared tight.

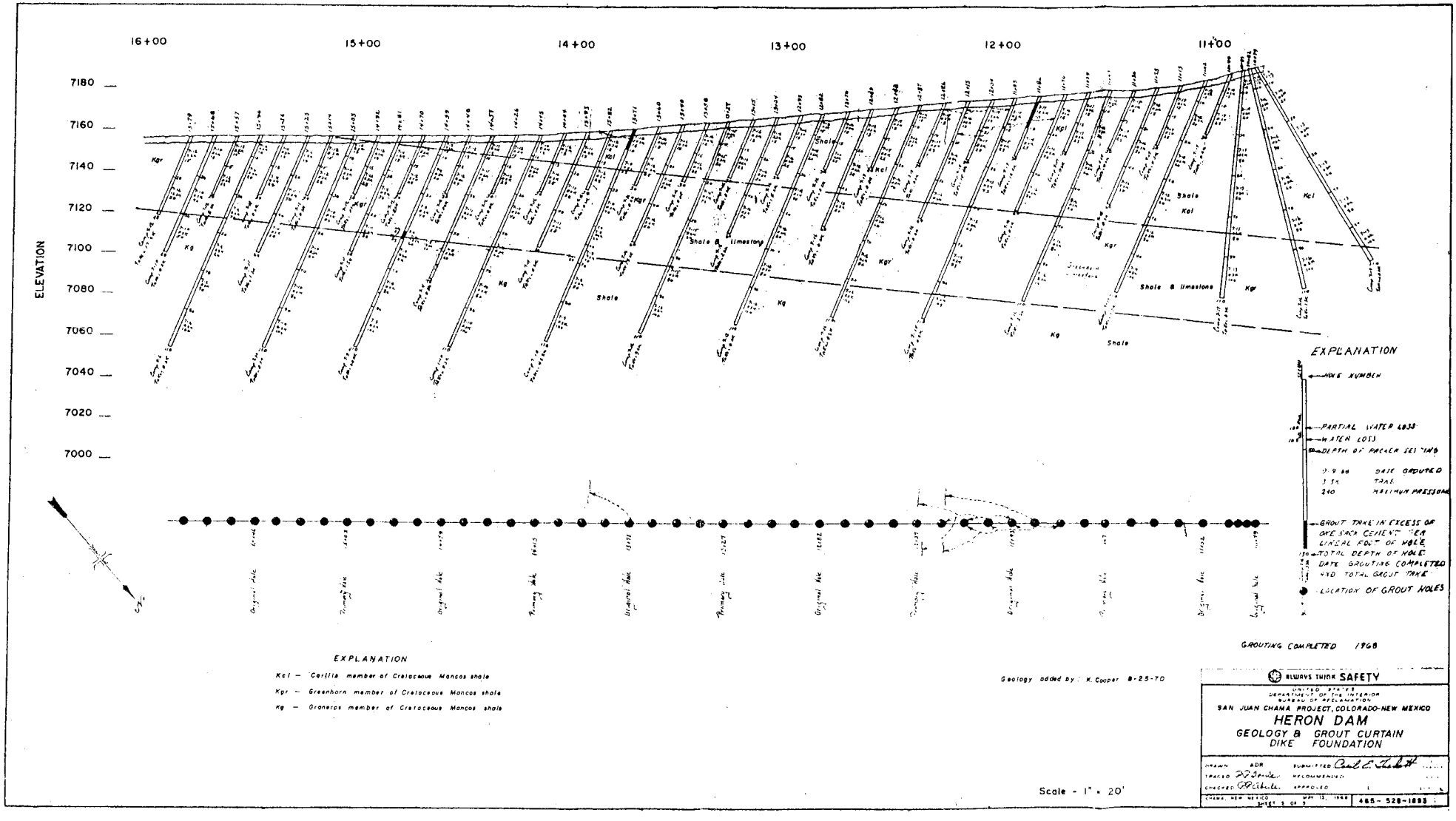
The reservoir basin is believed to be tight. However, some seepage may occur along joints and bedding planes in the Dakota and Mancos formations. Should seepage occur through the Dakota formation, it would likely appear on the right (north) side of Chama River a few hundred feet upstream and downstream of Willow Creek and in the canyon walls of Willow Creek downstream from the dam. Should seepage occur through the Mancos formation in the east rim of the reservoir, it would likely be indicated by appearance of much alkali in drainages on the right (north) side of Chama River upstream from the dam.

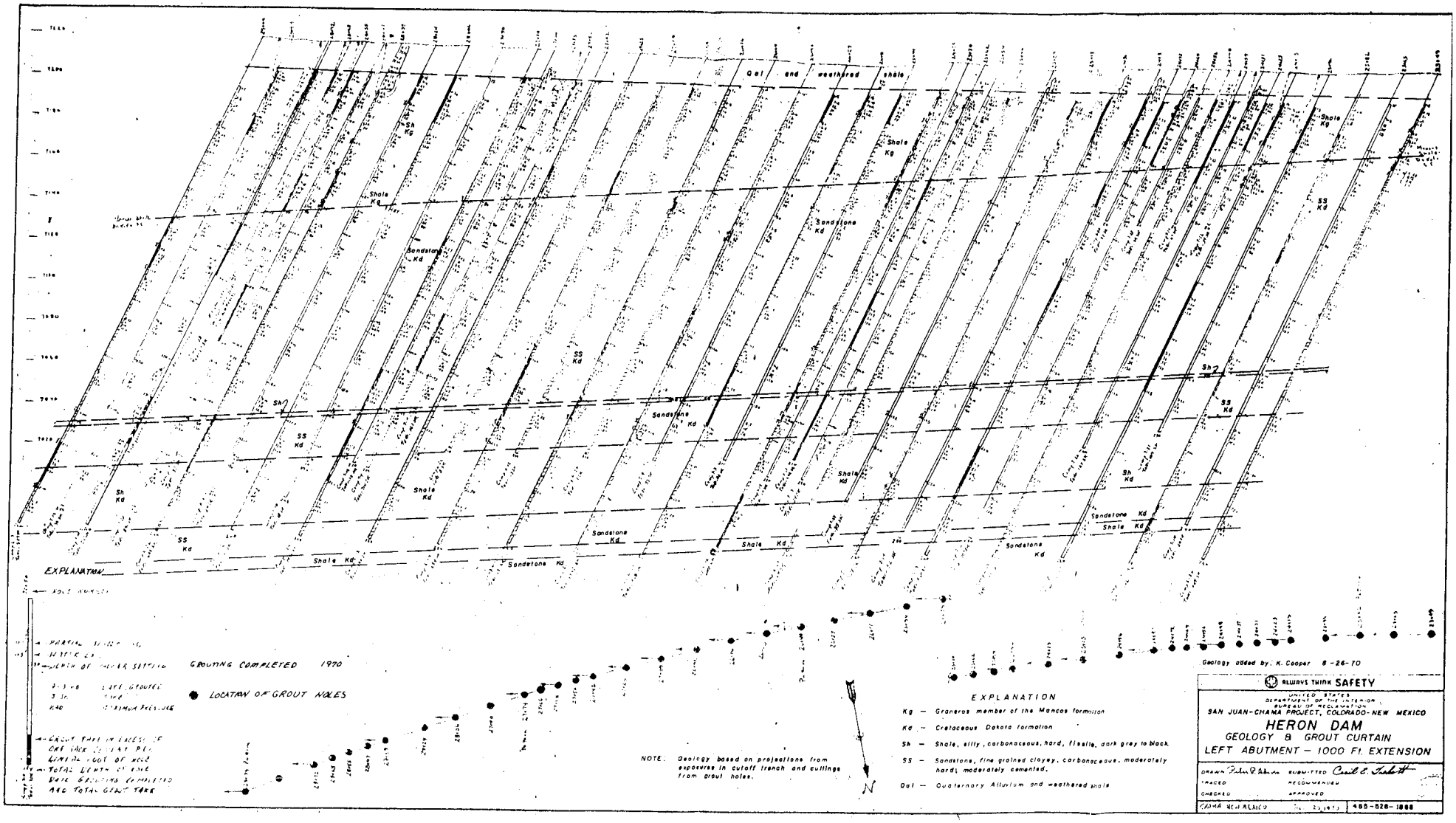

35
34
33
32
31
30
ELEVATION
7200
7180
7160
7140
7120
7100
7080
7060
7040
7020
7000
34+35
℄ Spillway
33+64
30+40
Concrete grout cap
Original ground surface
Kd
Sh
Shale
Sandstone
SS
PROFILE VIEW
PLAN VIEW
Scale - 1" = 20'
EXPLANATION
Kd - Cretaceous Dakota formation
Sh - Shale, clayey, silty, sandy, with beds of sandstone 1 to 2 inches thick in the upper part, bentonitic, with thin bentonitic beds, firm - to hard, fissile black. Sheared and fractured from sliding with many vertical fractures filled with limonite, gypsum and jarosite below elevation 7080 M.S.L.
SS - Sandstone, fine grained, silty, carbonaceous, moderately hard - breaks on a moderate blow with a hammer, moderately cemented, slightly friable, jointed, dark grey. Beds 1 to 2 inches thick, joints are tight, brown stained.
EXPLANATION
HOLE NUMBER
PWL PARTIAL WATER LOSS
WL WATER LOSS
52 DEPTH OF PACKER SETTING
DATE GROUTING COMPLETED AND TOTAL GROUT TAKE
SCALE 1" = 20'
Location of Grout Holes
Grouting Completed 1968
Geology added by: K. Cooper 8-25-70
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN CHAMA PROJECT, COLORADO - NEW MEXICO
HERON DAM
GEOLOGY & GROUT CURTAIN
DIKE FOUNDATION
DRAWN ADR
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
465-528-1889

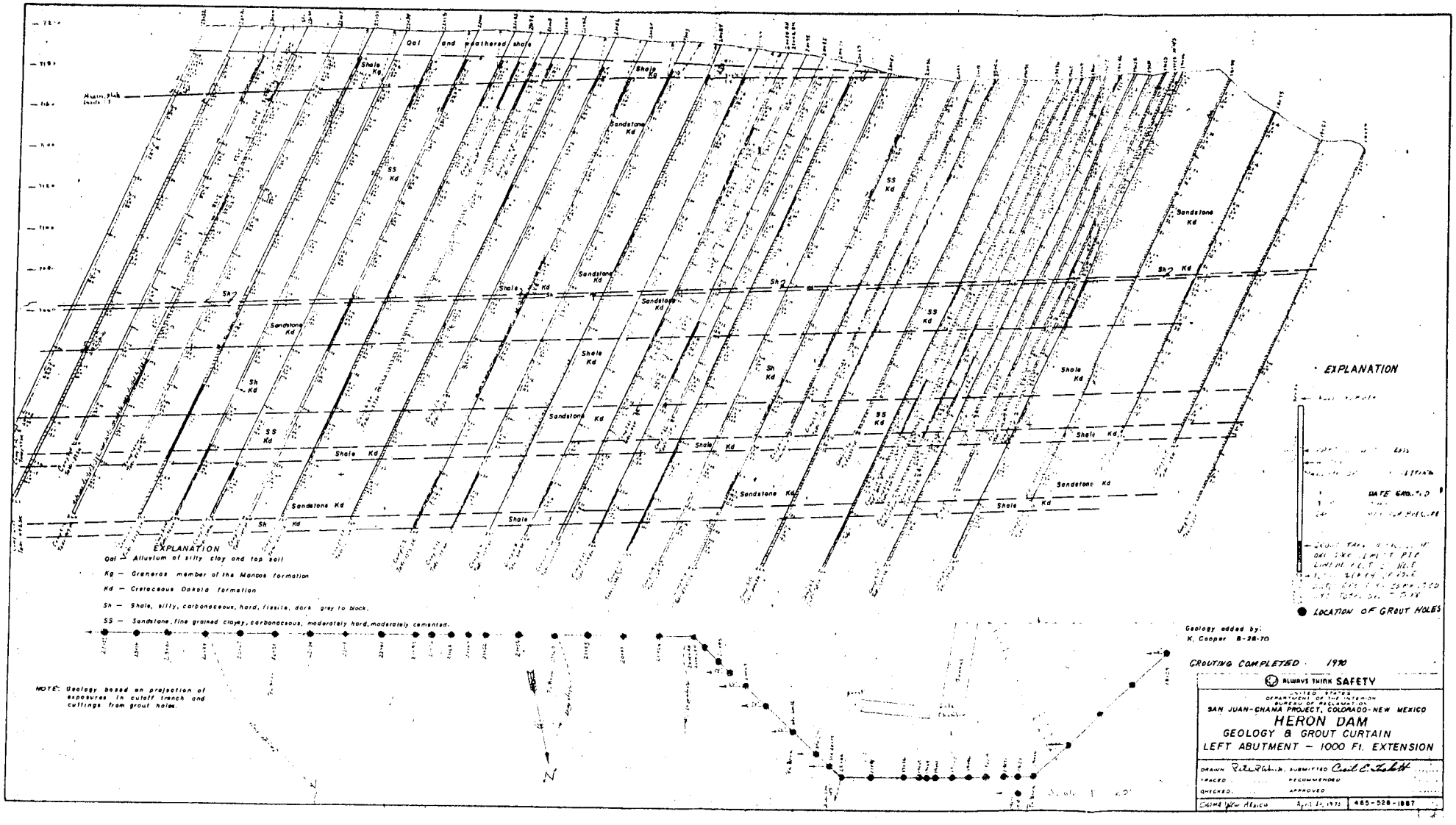

30
29
28
27
26
25
ELEVATION
7200
7180
7160
7140
7120
7100
7080
7060
7040
7020
7000
30+40
25+60
Original ground surface
Concrete grout cap
Sandstone
Shale
Kd
Sh
SS
EXPLANATION
Kd - Cretaceous Dakota formation
Sh - Shale, clayey, silty, sandy, with beds of sandstone 1 to 2 inches thick in the upper part, bentonitic, with thin bentonite beds, firm to hard, fissile black. Sheared and fractured from sliding with many vertical fractures filled with limonite, gypsum and jarosite below elevation 7080 M.S.L.
SS - Sandstone, fine grained, silty, carbonaceous, moderately hard - breaks on a moderate blow with a hammer, moderately cemented, slightly friable, jointed, dark grey. Beds 1 to 2 inches thick, joints are tight, brown stained.
EXPLANATION
HOLE NUMBER
PARTIAL WATER LOSS
WATER LOSS
DEPTH OF PACKER SETTING
GROUT
MAX. HOLE PRESSURE
HOLE
TOTAL DEPTH OF HOLE
COMPLETED
TRAP
-- Location of grout hole
Geology added by: K. Cooper 8-25-70
Completed grouting 1968
Scale - 1" = 20'
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN CHAMA PROJECT, COLORADO-NEW MEXICO
HERON DAM
GEOLOGY & GROUT CURTAIN
DIKE FOUNDATION
DRAWN ADR
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
CHAMA, NEW MEXICO
APRIL 23, 1969
SHEET 2 OF 2
465-528-1890

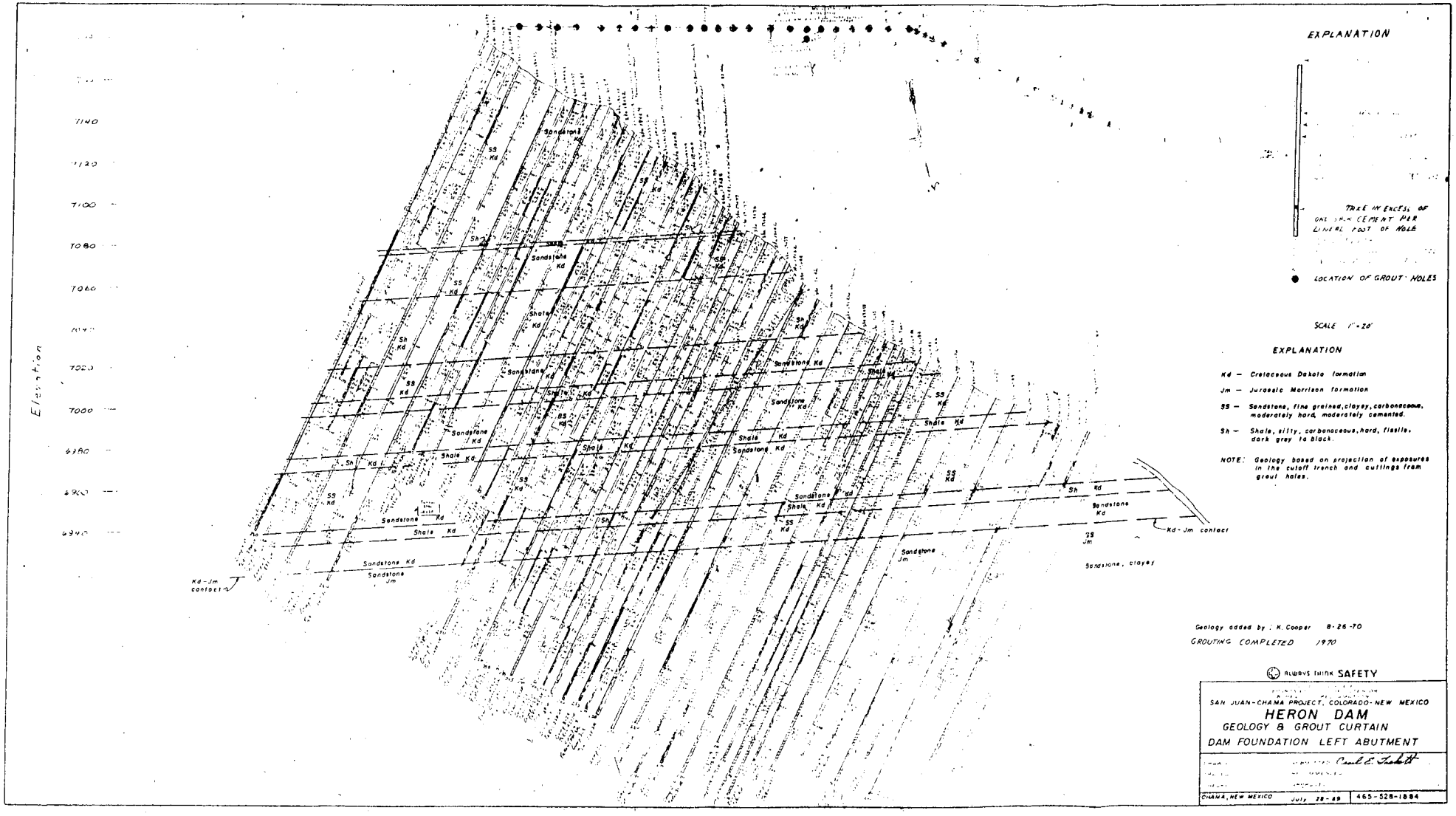

25+00
24+00
23+00
22+00
21+00
ELEVATION
7180
7160
7140
7120
7100
7080
7060
7040
7020
7000
25+60
EXPLANATION
Kg - Graneros member of the Cretaceous Mancos shale.
Kd - Cretaceous Dakota formation
Sh - Shale, clayey, silty, sandy, with beds of sandstone 1 to 2 inches thick in the upper part, bentonitic, with thin bentonitic beds, firm to hard, fissile black. Sheared and fractured from sliding with many vertical fractures filled with limonite, gypsum and jarosite below elevation 7080 M. SL.
SS - Sandstone, fine grained, silty, carbonaceous moderately hard - breaks on a moderate blow with a hammer, moderately cemented, slightly friable, jointed, dark gray. Beds 1 to 2 inches thick, joints are light, brown stained.
Approximate contact of Kg-Kd
Sandstone Kd
Shale Kg
Shale Kd
Sandstone
Sh
SS
EXPLANATION
HOLE NUMBER
PARTIAL WATER LOSS
WATER LOSS
DEPTH OF PACKER SETTING
DATE GROUTED
TAKE
MAXIMUM PRESSURE
GROUT TAKE IN EXCESS OF ONE SACK CEMENT PER LINEAL FOOT OF HOLE
TOTAL DEPTH OF HOLE
DATE GROUTING COMPLETED AND TOTAL GROUT TAKE
LOCATION OF GROUT HOLES
Geology added by K. Cooper 8-25-70
GROUT COMPLETED 1968
Scale - 1" = 20'
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN-CHAMA PROJECT, COLORADO-NEW MEXICO
HERON DAM
GEOLOGY & GROUT CURTAIN
DIKE FOUNDATION
DRAWN ADR
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
CHAMA, NEW MEXICO
SHEET 1 OF 8
465-828-1001

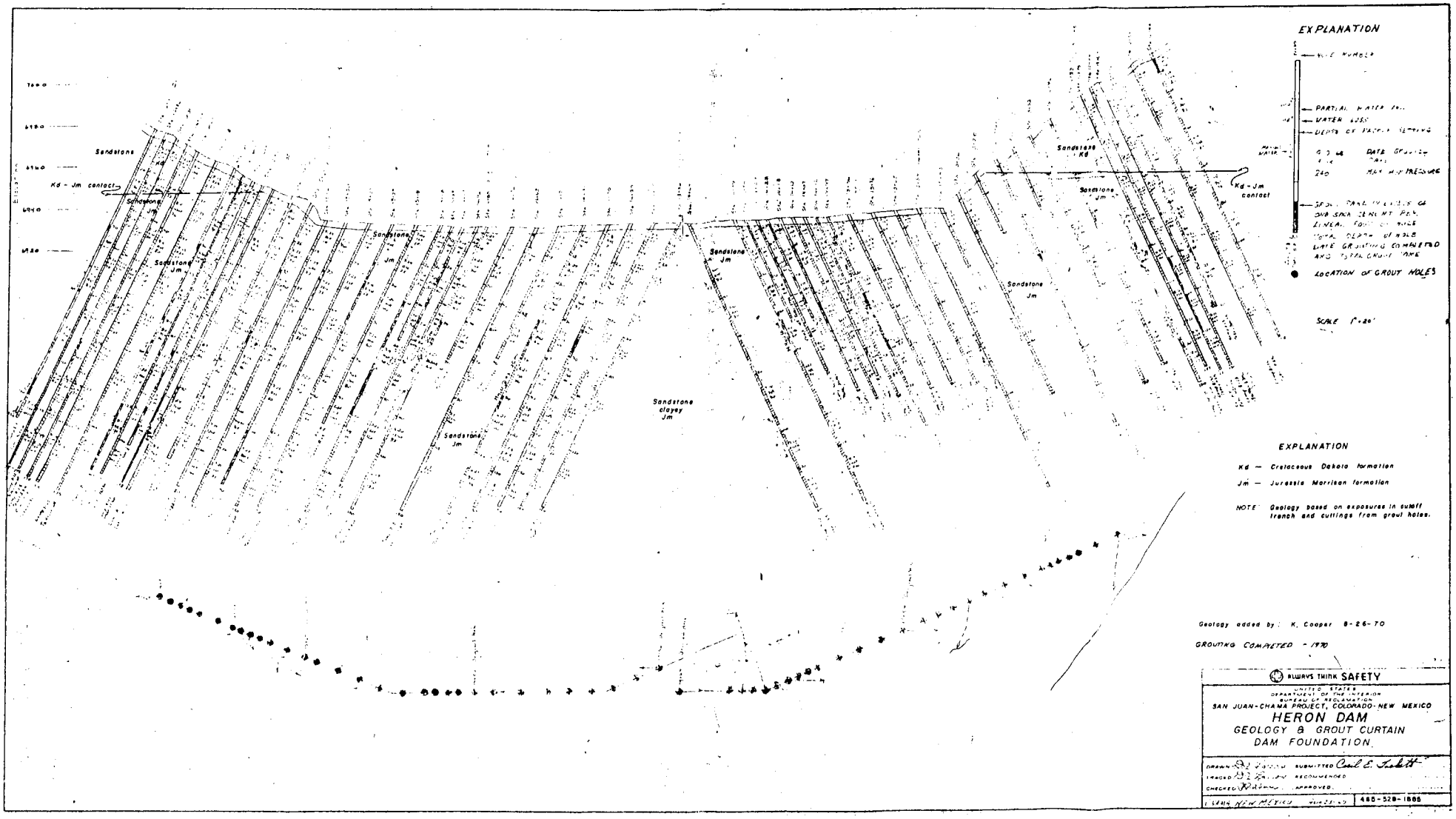

21+00
20+00
19+00
18+00
17+00
16+00
ELEVATION
7180
7160
7140
7120
7100
7080
7060
7040
7020
7000
Kgr
Kg
Kd
Shale & Limestone
Shale
Sandstone
EXPLANATION
Kgr — Greenhorn member of Cretaceous Mancos shale
Kg — Graneros member of Cretaceous Mancos shale
Kd — Cretaceous Dakota formation
EXPLANATION
HOLE NUMBER
PARTIAL WATER LOSS
WATER LOSS
DEPTH OF PACKER SETTING
DATE GROUTED
MAXIMUM PRESSURE
GROUT TAKE IN EXCESS OF ONE SACK CEMENT PER LINEAL FOOT OF HOLE
TOTAL DEPTH OF HOLE
DATE GROUTING COMPLETED AND TOTAL GROUT TAKE
LOCATION OF GROUT HOLES
Geology added by: K. Cooper 8-25-70
GROUTING COMPLETED 1968
Scale - 1" = 20'
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN CHAMA PROJECT, COLORADO-NEW MEXICO
HERON DAM
GEOLOGY & GROUT CURTAIN
DIKE FOUNDATION
DRAWN ADR
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
CHAMA, NEW MEXICO
SHEET 4 OF 7
MAY 13, 1968
465-528-1892

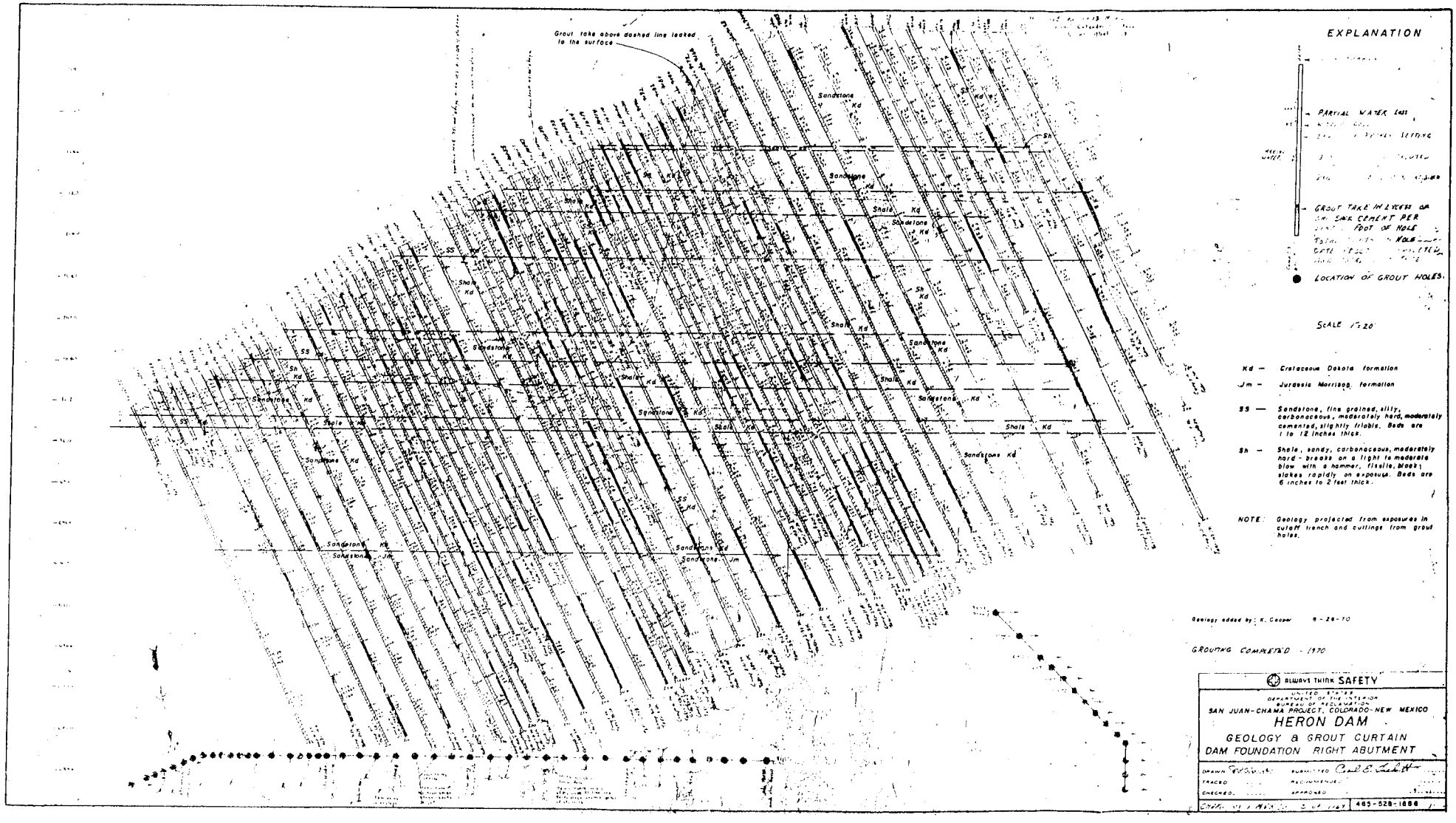

16+00
15+00
14+00
13+00
12+00
11+00
ELEVATION
7180
7160
7140
7120
7100
7080
7060
7040
7020
7000
Kgr
Kg
Kcl
Shale
Shale & limestone
Shale & limestone
EXPLANATION
HOLE NUMBER
PARTIAL WATER LOSS
WATER LOSS
DEPTH OF PACKER SETTING
DATE GROUTED
TAKE
MAXIMUM PRESSURE
GROUT TAKE IN EXCESS OF ONE SACK CEMENT PER LINEAL FOOT OF HOLE
TOTAL DEPTH OF HOLE
DATE GROUTING COMPLETED AND TOTAL GROUT TAKE
LOCATION OF GROUT HOLES
Original Hole
Primary Hole
GROUTING COMPLETED 1968
EXPLANATION
Kcl — Carlile member of Cretaceous Mancos shale
Kgr — Greenhorn member of Cretaceous Mancos shale
Kg — Graneros member of Cretaceous Mancos shale
Geology added by: K. Cooper 8-25-70
Scale - 1" = 20'
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN CHAMA PROJECT, COLORADO-NEW MEXICO
HERON DAM
GEOLOGY & GROUT CURTAIN
DIKE FOUNDATION
DRAWN ADR
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
CHAMA, NEW MEXICO
MAY 13, 1968
SHEET 3 OF 3
485-528-1893

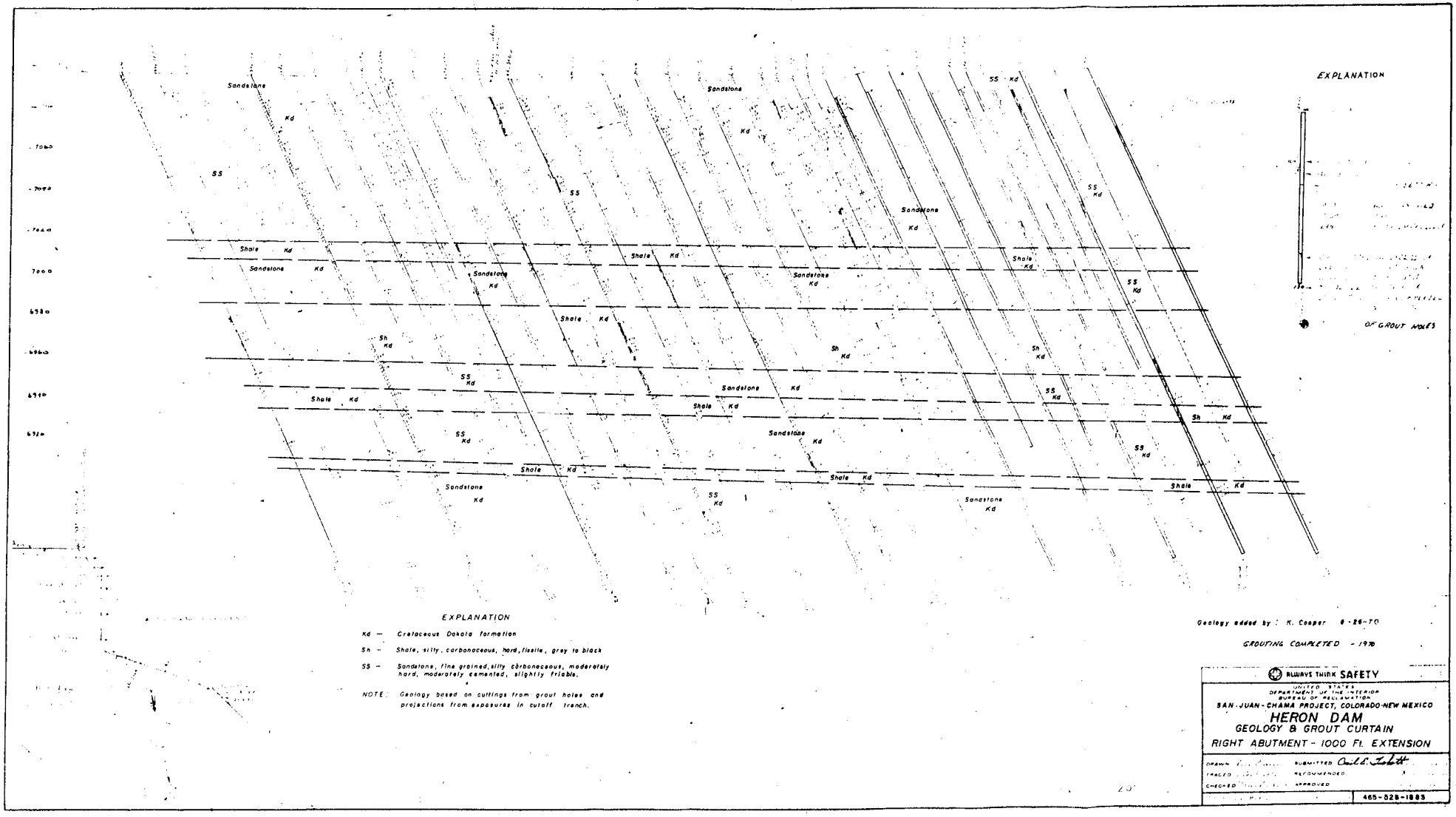

Qal and weathered shale
Shale Kg
Sandstone Kd
SS Kd
Sh Kd
Shale Kd
Sandstone Kd
Shale Kd
Sh?
EXPLANATION
GROUTING COMPLETED 1970
LOCATION OF GROUT HOLES
NOTE: Geology based on projections from exposures in cutoff trench and cuttings from grout holes.
EXPLANATION
Kg — Graneros member of the Mancos formation
Kd — Cretaceous Dakota formation
Sh — Shale, silty, carbonaceous, hard, fissile, dark grey to black
SS — Sandstone, fine grained clayey, carbonaceous, moderately hard; moderately cemented.
Qal — Quaternary Alluvium and weathered shale
Geology added by: K. Cooper 8-26-70
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN-CHAMA PROJECT, COLORADO-NEW MEXICO
HERON DAM
GEOLOGY & GROUT CURTAIN
LEFT ABUTMENT — 1000 Ft. EXTENSION
DRAWN
SUBMITTED
TRACED
RECOMMENDED
CHECKED
APPROVED
CHAMA NEW MEXICO
485-528-1868

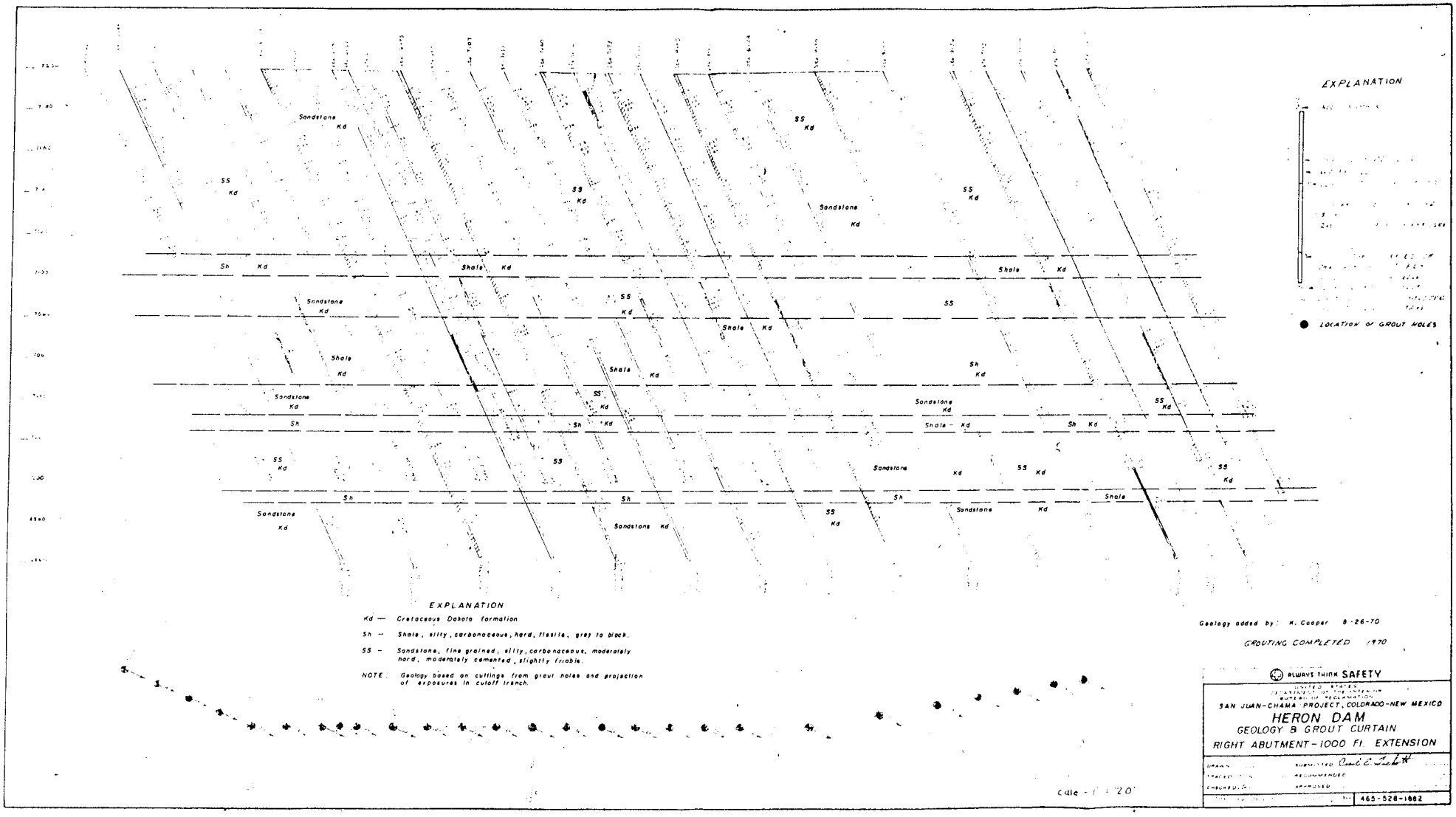

Qal and weathered shale
Shale Kd
Sandstone Kd
SS Kd
Sh Kd
EXPLANATION
Qal — Alluvium of silty clay and top soil
Kg — Graneros member of the Mancos formation
Kd — Cretaceous Dakota formation
Sh — Shale, silty, carbonaceous, hard, fissile, dark grey to black.
SS — Sandstone, fine grained clayey, carbonaceous, moderately hard, moderately cemented.
NOTE: Geology based on projection of exposures in cutoff trench and cuttings from grout holes.
EXPLANATION
LOCATION OF GROUT HOLES
Geology added by:
K. Cooper 8-28-70
GROUTING COMPLETED 1970
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN-CHAMA PROJECT, COLORADO-NEW MEXICO
HERON DAM
GEOLOGY & GROUT CURTAIN
LEFT ABUTMENT – 1000 Ft. EXTENSION
DRAWN
SUBMITTED
TRACED
RECOMMENDED
CHECKED
APPROVED
465-528-1887


EXPLANATION
TAKE IN EXCESS OF ONE SACK CEMENT PER LINEAL FOOT OF HOLE
LOCATION OF GROUT HOLES
SCALE 1" = 20'
EXPLANATION
Kd — Cretaceous Dakota formation
Jm — Jurassic Morrison formation
SS — Sandstone, fine grained, clayey, carbonaceous, moderately hard, moderately cemented.
Sh — Shale, silty, carbonaceous, hard, fissile, dark grey to black.
NOTE: Geology based on projection of exposures in the cutoff trench and cuttings from grout holes.
Elevation
7140
7120
7100
7080
7060
7040
7020
7000
6980
6960
6940
Sandstone Kd
Shale Kd
Sandstone Jm
Kd-Jm contact
Sandstone, clayey
Geology added by: K. Cooper 8-26-70
GROUTING COMPLETED 1970
ALWAYS THINK SAFETY
SAN JUAN-CHAMA PROJECT, COLORADO-NEW MEXICO
HERON DAM
GEOLOGY & GROUT CURTAIN
DAM FOUNDATION LEFT ABUTMENT
CHAMA, NEW MEXICO
July 28-69
465-528-1884


EXPLANATION
PARTIAL WATER LOSS
WATER LOSS
DEPTH OF PARTIAL SEALING
DATE GROUTING COMPLETED AND TOTAL GROUT TAKE
LOCATION OF GROUT HOLES
SCALE 1"=20'
Sandstone Kd
Kd - Jm contact
Sandstone Jm
Sandstone clayey Jm
EXPLANATION
Kd — Cretaceous Dakota formation
Jm — Jurassic Morrison formation
NOTE: Geology based on exposures in cutoff trench and cuttings from grout holes.
Geology added by: K. Cooper 8-26-70
GROUTING COMPLETED - 1970
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN-CHAMA PROJECT, COLORADO-NEW MEXICO
HERON DAM
GEOLOGY & GROUT CURTAIN
DAM FOUNDATION
SUBMITTED
RECOMMENDED
APPROVED
NEW MEXICO
480-528-1888


Grout take above dashed line leaked to the surface
Sandstone Kd
Shale Kd
Sandstone Jm
Sh
SS
EXPLANATION
PARTIAL WATER LOSS
GROUT TAKE IN LYCESS OF SACK CEMENT PER FOOT OF HOLE
LOCATION OF GROUT HOLES.
SCALE 1"=20'
Kd — Cretaceous Dakota formation
Jm — Jurassic Morrison formation
SS — Sandstone, fine grained, silty, carbonaceous, moderately hard, moderately cemented, slightly friable. Beds are 1 to 12 inches thick.
Sh — Shale, sandy, carbonaceous, moderately hard - breaks on a light to moderate blow with a hammer, fissile, blocky; slakes rapidly on exposure. Beds are 6 inches to 2 feet thick.
NOTE: Geology projected from exposures in cutoff trench and cuttings from grout holes.
Geology added by: K. Cooper 9-28-70
GROUTING COMPLETED - 1970
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN-CHAMA PROJECT, COLORADO-NEW MEXICO
HERON DAM
GEOLOGY & GROUT CURTAIN
DAM FOUNDATION RIGHT ABUTMENT
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
465-528-1886


EXPLANATION
OF GROUT HOLES
Sandstone
Kd
SS
Shale
Sh
EXPLANATION
Kd — Cretaceous Dakota formation
Sh — Shale, silty, carbonaceous, hard, fissile, grey to black
SS — Sandstone, fine grained, silty carbonaceous, moderately hard, moderately cemented, slightly friable.
NOTE: Geology based on cuttings from grout holes and projections from exposures in cutoff trench.
Geology added by: K. Cooper 8-26-70
GROUTING COMPLETED - 1970
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN-JUAN-CHAMA PROJECT, COLORADO-NEW MEXICO
HERON DAM
GEOLOGY & GROUT CURTAIN
RIGHT ABUTMENT - 1000 Ft. EXTENSION
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
465-D28-1883


EXPLANATION
LOCATION OF GROUT HOLES
Sandstone
Kd
SS
Sh
Shale
EXPLANATION
Kd — Cretaceous Dakota formation
Sh — Shale, silty, carbonaceous, hard, fissile, grey to black.
SS — Sandstone, fine grained, silty, carbonaceous, moderately hard, moderately cemented, slightly friable.
NOTE: Geology based on cuttings from grout holes and projection of exposures in cutoff trench.
Geology added by: H. Cooper 8-26-70
GROUTING COMPLETED 1970
Scale - 1" = 20'
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN-CHAMA PROJECT, COLORADO-NEW MEXICO
HERON DAM
GEOLOGY & GROUT CURTAIN
RIGHT ABUTMENT-1000 Ft. EXTENSION
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
465-528-1882

APPENDIX C

DOCUMENTS REVIEWED FOR HERON DAM AND DIKE

1. Final report on foundation and outlet works grouting, Heron Dam and Dike, January 1971.

2. Final Construction Geology Report of Heron Dam, October 1970.

3. Heron Dam and Dike specifications, paragraphs 93 through 102, pressure grouting.

4. Drilling and grouting reports L-10. Monthly reports for the period of April 1968 to August 31, 1970.

5. Letters related to contract claim of changed conditions for grouting.

6. Geologic logs of Heron Dam drill holes 1 through 34.

7. Geologic logs of Heron Dike drill holes 1 through 10.

8. Design Data, Heron Dam, Volume III, Para. 133.4.2D Foundation Data (Geology).

9. Instrumentation history, 2 pages with piezometer plots 1970-1981.

10. Technical data workbook, Heron Dam, prepared by Converse Ward Davis Dixon, Inc., September 26, 1980.

11. Draft SEED report of Heron Dam. July 21, 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.