GLEN CANYON DAM SPILLWAY TUNNEL REPAIRS, 1983 - 1984

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Reference USBR Final Construction Report.

Contract No. 3-CC-40-01100

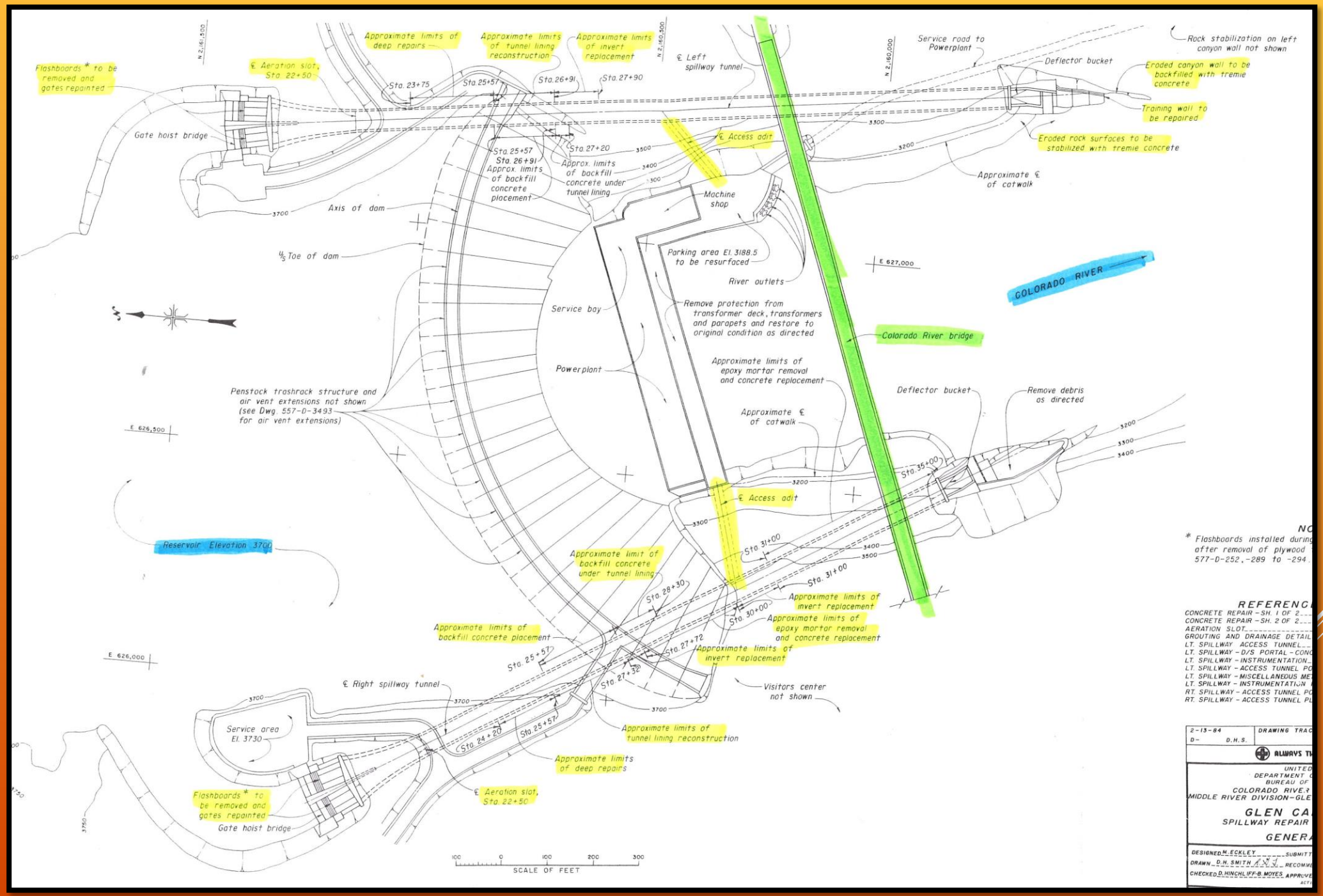
Disclaimer:
This presentation is not a technical, engineering, nor historical record of the actual, sequential events that took place. It is meant as an informational piece to help the general public have some rough understanding of the events that took place in 1983 and '84. For the precise details please refer to the USBR's Final Construction Report.

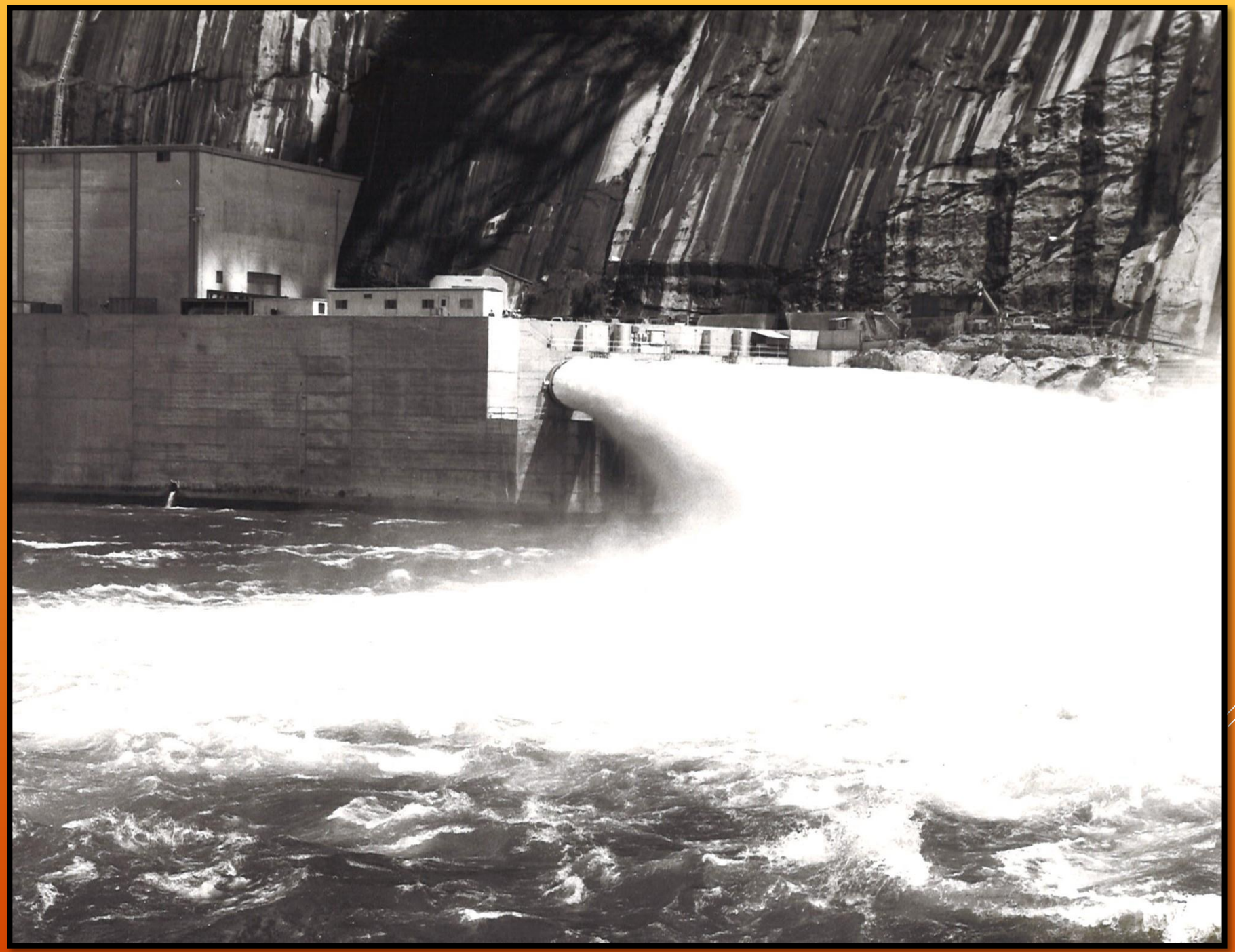
Glen Canyon Dam:

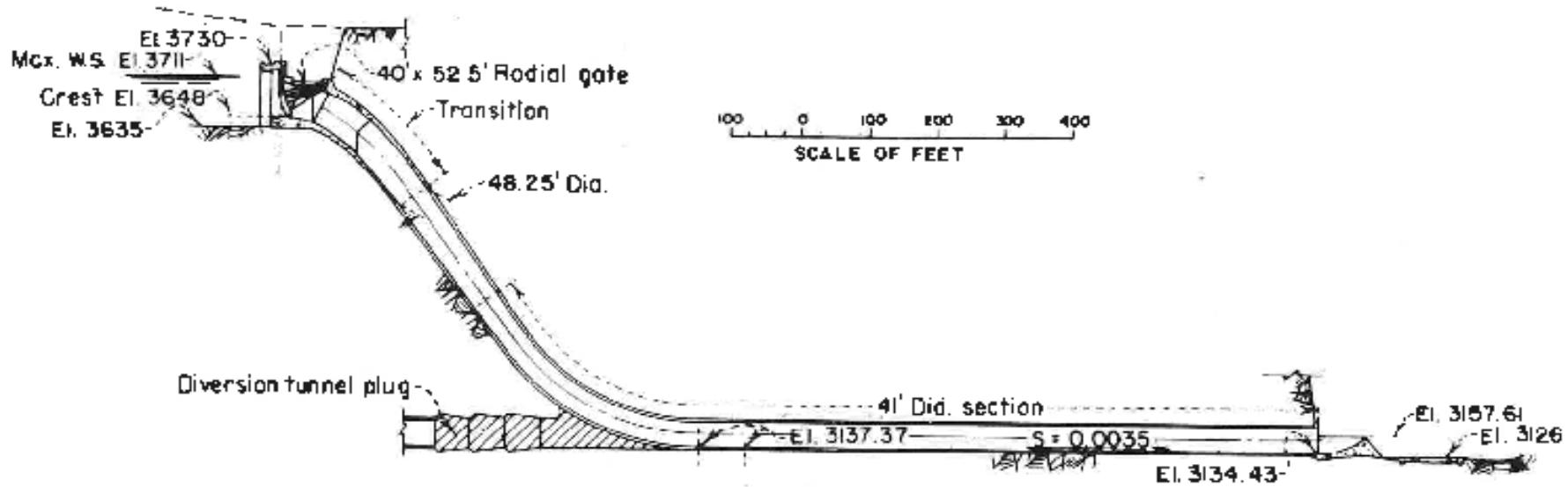
Glen Canyon Dam is a concrete arch-gravity dam on the Colorado River in northern Arizona, near the town of Page. The 710-foot high dam was built by the U.S. Bureau of Reclamation (USBR) from 1956 to 1966 and forms Lake Powell, one of the largest man-made reservoirs in the U.S. with a capacity of 27 million acre feet. The dam is named for Glen Canyon, a series of deep sandstone gorges now flooded by the reservoir; Lake Powell is named for John Wesley Powell, who in 1869 led the first expedition to traverse the Colorado's Grand Canyon by boat.

The Set Up:

During the El Niño winter of 1982–1983, the Bureau of Reclamation predicted an average runoff for the Colorado River. However, snowfall during April and May was exceptionally heavy; this combined with a sudden rise in temperatures and unusual rainstorms in June to produce major flooding across the western United States. With Lake Powell nearly full, the USBR did not have enough time to draw down the reservoir to accommodate extra runoff. By mid-June, water was pouring into Lake Powell at over 120,000 cubic feet per second. Even with the power plant and river outlet works running at full capacity, Lake Powell continued to rise to the point where the spillways had to be opened. Other than a brief test in 1980, this was the only time the spillways had ever been used.


Approximate limits of deep repairs
Approximate limits of tunnel lining reconstruction
Approximate limits of invert replacement
℄ Left spillway tunnel
Service road to Powerplant
Rock stabilization on left canyon wall not shown
Deflector bucket
Eroded canyon wall to be backfilled with tremie concrete
Training wall to be repaired
Eroded rock surfaces to be stabilized with tremie concrete
Approximate ℄ of catwalk
Flashboards * to be removed and gates repainted
℄ Aeration slot, Sta. 22+50
Sta. 23+75
Sta. 25+57
Sta. 26+91
Sta. 27+90
Gate hoist bridge
Sta. 25+57
Sta. 26+91
Approx. limits of backfill concrete placement
Sta. 27+20
Approx. limits of backfill concrete under tunnel lining
℄ Access adit
Machine shop
Axis of dam
U/S Toe of dam
Parking area El. 3188.5 to be resurfaced
River outlets
E 627,000
COLORADO RIVER
Service bay
Remove protection from transformer deck, transformers and parapets and restore to original condition as directed
Colorado River bridge
Powerplant
Approximate limits of epoxy mortar removal and concrete replacement
Deflector bucket
Remove debris as directed
Penstock trashrack structure and air vent extensions not shown (see Dwg. 557-D-3493 for air vent extensions)
Approximate ℄ of catwalk
E 626,500
Sta. 35+00
℄ Access adit
Reservoir Elevation 3700
Approximate limit of backfill concrete under tunnel lining
Sta. 31+00
Sta. 28+30
Approximate limits of invert replacement
Sta. 30+00
Approximate limits of epoxy mortar removal and concrete replacement
Approximate limits of backfill concrete placement
Sta. 27+72
Approximate limits of invert replacement
Sta. 25+57
Sta. 27+32
E 626,000
℄ Right spillway tunnel
Visitors center not shown
Service area El. 3730
Sta. 24+20
Sta. 25+57
Approximate limits of tunnel lining reconstruction
Approximate limits of deep repairs
℄ Aeration slot, Sta. 22+50
Flashboards * to be removed and gates repainted
Gate hoist bridge
100 0 100 200 300
SCALE OF FEET
* Flashboards installed during
after removal of plywood
577-D-252,-289 to -294.
REFERENCE
CONCRETE REPAIR - SH. 1 OF 2
CONCRETE REPAIR - SH. 2 OF 2
AERATION SLOT
GROUTING AND DRAINAGE DETAIL
LT. SPILLWAY ACCESS TUNNEL
LT. SPILLWAY - D/S PORTAL - CONC
LT. SPILLWAY - INSTRUMENTATION
LT. SPILLWAY - ACCESS TUNNEL PO
LT. SPILLWAY - MISCELLANEOUS ME
LT. SPILLWAY - INSTRUMENTATION
RT. SPILLWAY - ACCESS TUNNEL PO
RT. SPILLWAY - ACCESS TUNNEL PL
2-13-84
D- D.H.S.
DRAWING TRAC
ALWAYS TH
UNITED
DEPARTMENT
BUREAU OF
COLORADO RIVER
MIDDLE RIVER DIVISION-GLE
GLEN CA
SPILLWAY REPAIR
GENERA
DESIGNED M. ECKLEY
DRAWN D.H. SMITH
CHECKED D. HINCHLIFF-B. MOYES
SUBMITT
RECOMM
APPROVE





SECTION THRU RIGHT SPILLWAY TUNNEL

The Event:

At the beginning of June, dam operators opened the gates on the left spillway, sending 10,000 cfs, less than one-tenth of capacity, down the tunnel and into the river below. After a few days, the entire dam suddenly began to shake violently. The spillway was closed down for inspections and workers discovered that the flow of water was causing cavitation — which was damaging the concrete lining and eroding the spillway..

The Results:

To delay having to use the spillways, the USBR installed plywood flashboards (later replaced by steel) atop the gates to increase the lake level. Even this additional capacity was exhausted. At Lee's Ferry, the Colorado River peaked at 97,300 cubic feet per second, which was and still is the highest water flow recorded there since the dam was built. Just as it seemed inevitable that the lake would overtop the gates, inflows fell and the potential disaster was averted. Upon inspection, it was found that cavitation had caused massive gouging damage to both spillways, carrying away thousands of tons of concrete, steel rebar and huge chunks of rock.

Overview:

Repairs to the spillways commenced as soon as possible and continued well into 1984. Air slots were installed in each spillway to absorb the shock of the bubbles formed by cavitation.

In 1984, the Colorado River basin produced even more runoff than 1983, peaking at 148,000 cubic feet per second in early June. This time, the USBR had drawn down the reservoir enough that it absorbed most of the early high flows. Nevertheless, Lake Powell rapidly approached the top of the spillway gates and construction efforts were subsequently focused on the left spillway in order to get it in operation in time. On August 12, the left spillway gates were opened, releasing water at a rate of 50,000 cubic feet per second. The repaired spillway was undamaged, proving the worth of the re-engineering and suggesting that Glen Canyon Dam will also be able to hold against future floods with the magnitude of 1983.

THE PROBLEM

On June 6, 1983, due to increased flow into Lake Powell, the discharge from the left spillway at Glen Canyon Dam was increased to 20,000 cfs.

Rumbling noises were heard and material was observed in the discharge.

Denver Engineers flew to page that same afternoon.

The left spillway gate was closed to avoid further tunnel damage.

A limited inspection was performed and damage was observed near the lowest portion of the concrete diversion plug.

By 6 pm that day it was decided that 4 foot high plywood flashboards would be installed on top of the LEFT radial gates to increase the lake capacity and avoid further use of the damaged tunnels.

The time frame given was 24 hours and at 8 pm that evening USBR personnel were back on-site to begin the work.

The crews worked until 4 am – went home for a shower and were back at 7 am. They completed the flashboards at 4 pm – just 22 hours after the decision was made.

The Arizona Republic

In 1983, plywood was all that kept Glen Canyon Dam from overflowing

Four days later, on June 10th, the decision was made to add plywood flashboards to the RIGHT spillway gates.

Since the lake water was close to the top of the radial gates and splashing over the gates, it was necessary to raise the gates a few inches so that the top of the gate would be dry for installation.

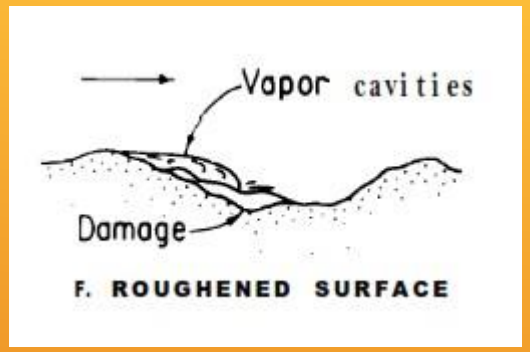
This meant that water was flowing under the gates while workers were installing the flashboards. This work was also completed within 24 hours and the gates were closed.

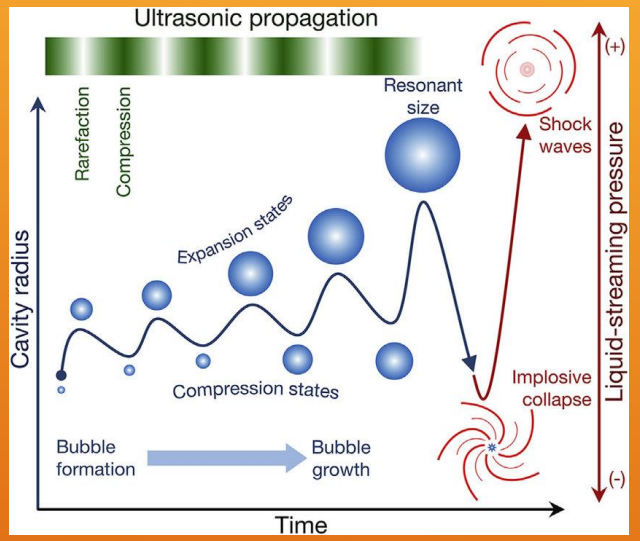
However the lake continued to rise and the gates were raised so that the flashboards would not be overtopped, but this undoubtably led to more damage within the tunnels.

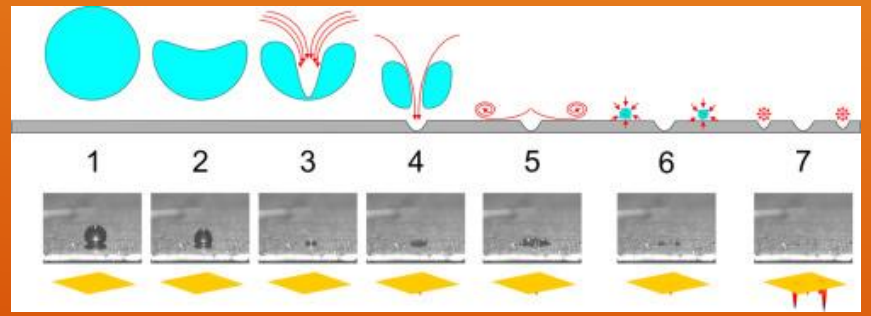
Later these 4 foot plywood flashboards were replaced by 8 foot tall steel gate extensions.

Lake Powell peaked on July 17, 1983 at an elevation of 3708.24. On July 23rd the gates were closed and provisions were made for inspecting the tunnels.

THE DAMAGE AND REPAIRS







The Cavitation Process

The Cavitation "Christmas Tree"

Cavitation and the USBR's spillways:

Hoover Dam's similar high head spillways were first used in 1941 an upon an inspection extensive cavitation and erosion had occurred. A comparison:

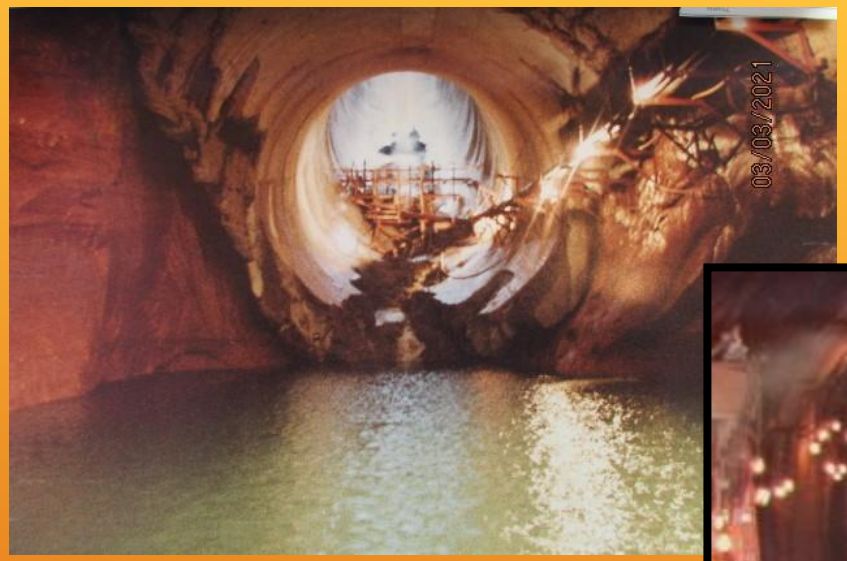
Hoover Dam, 1941. Erosion = 115' x 30' x 46' deep
Glen Canyon, 1983. Erosion = 135' x 25' x 50' deep.

Yellowtail Dam – In 1967-68, an aeration slot was added.

Glen Canyon – Plans were already underway and design data had been collected to add the aeration slots.

Flaming Gorge Dam – Slot added in 1982-83.

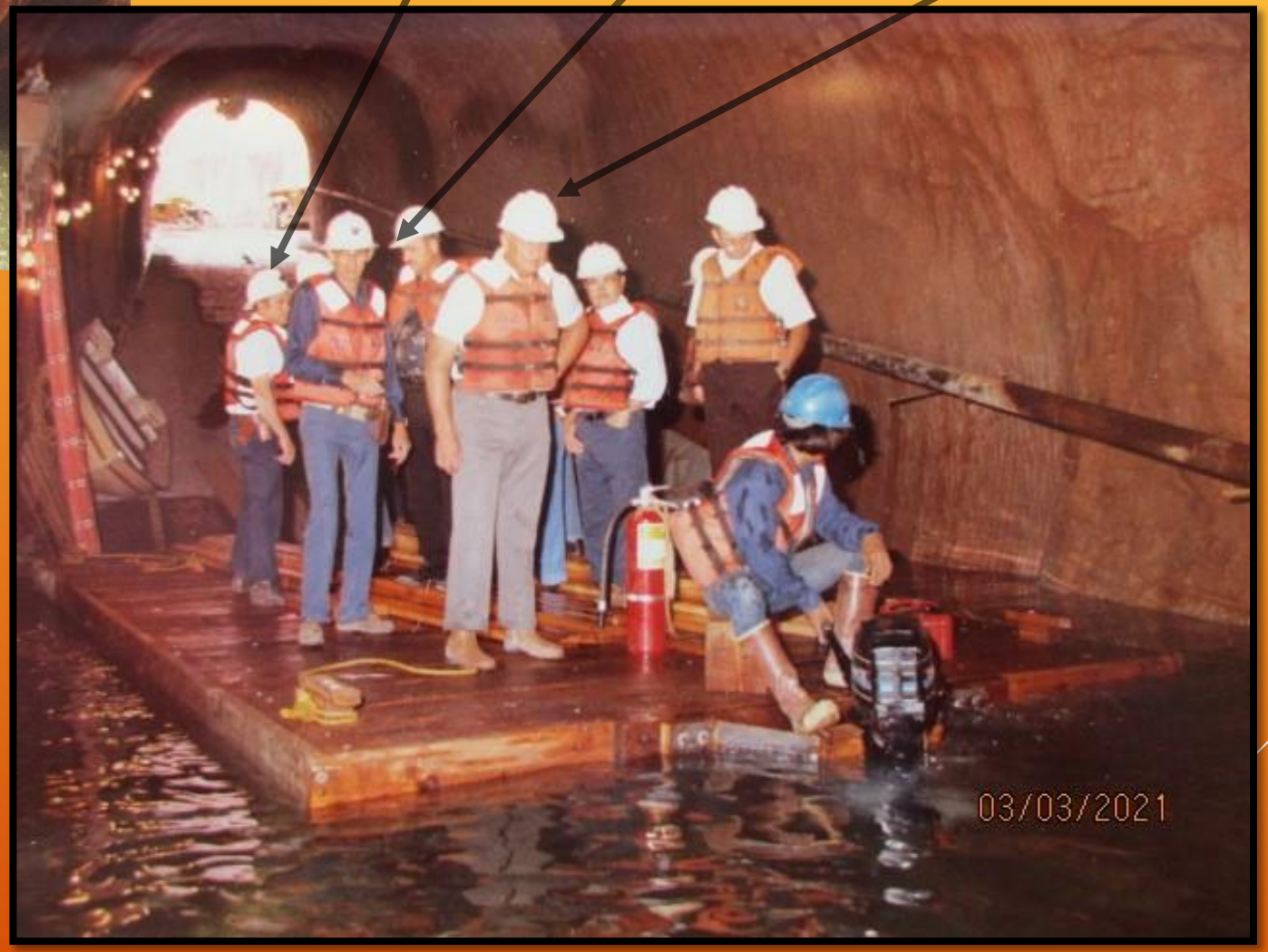
Aftermath – Aeration slots were installed after 1983 as a result of the Glen Canyon cavitation at Hoover Dam and others.



Bill McCormick

Art Graff

Bill Wyatt



First Responders

Intact Concrete Lining

Exposed Rebar

Navajo Sandstone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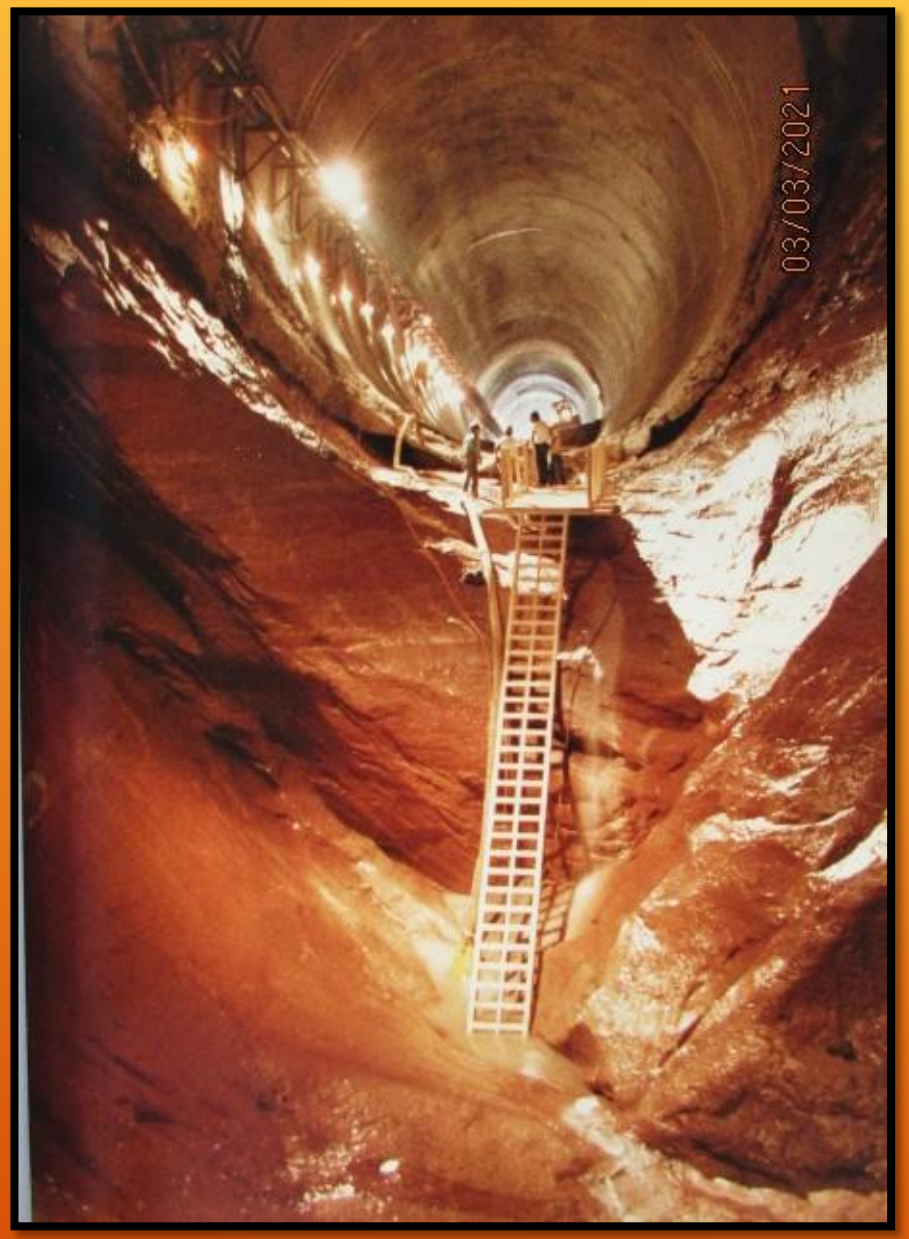
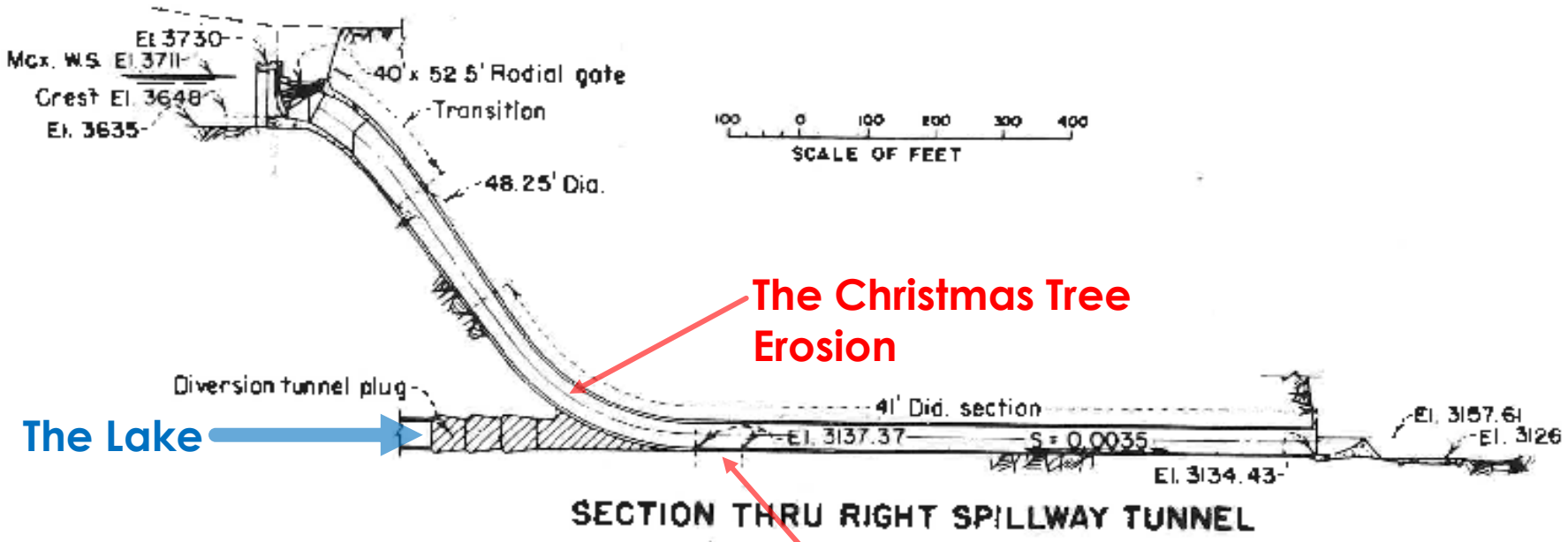


The “Hole” after dewatering, 30 to 40’ deep.

Rubble at the downstream portal.

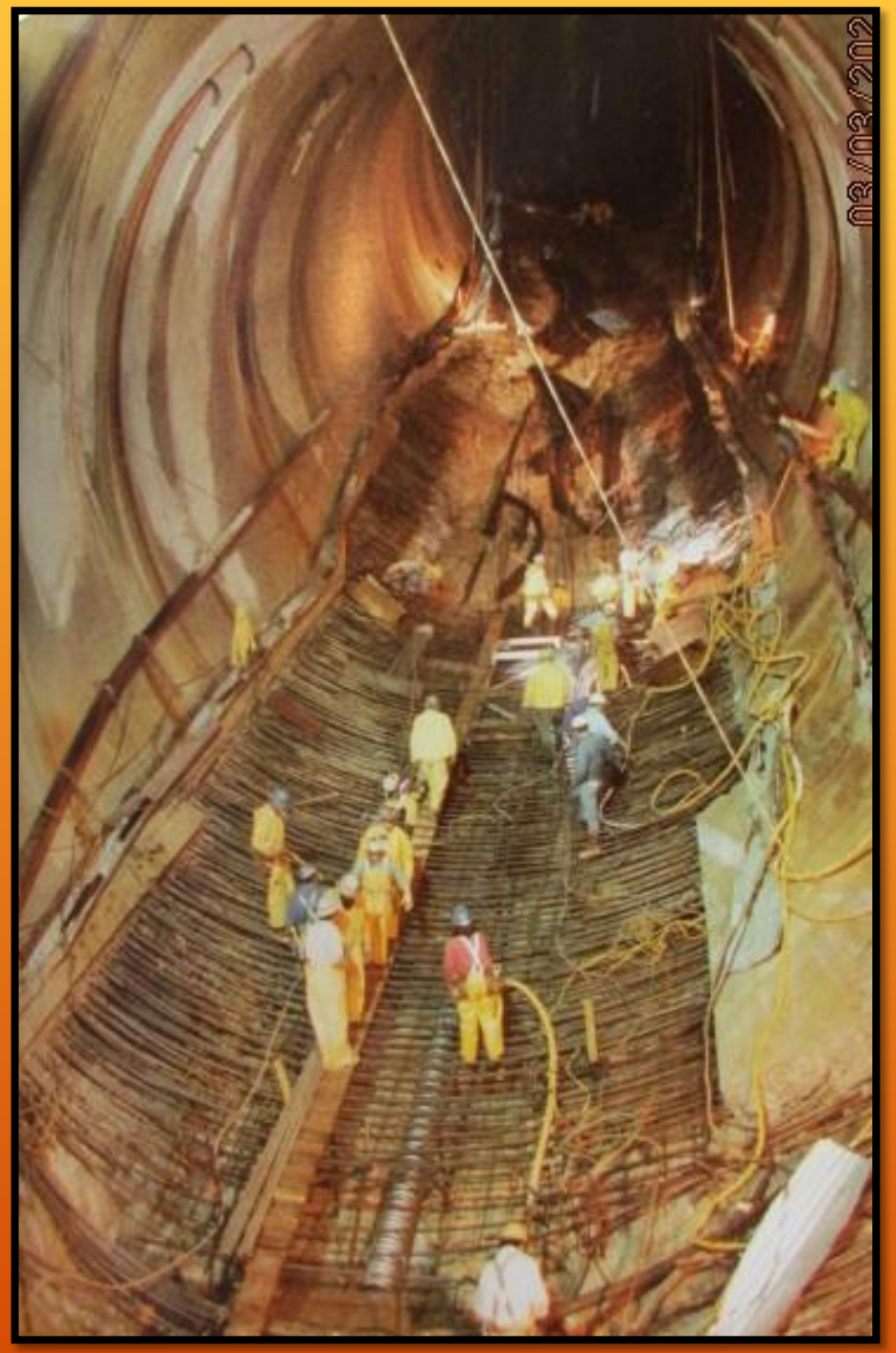


The Christmas Tree Erosion

The Lake

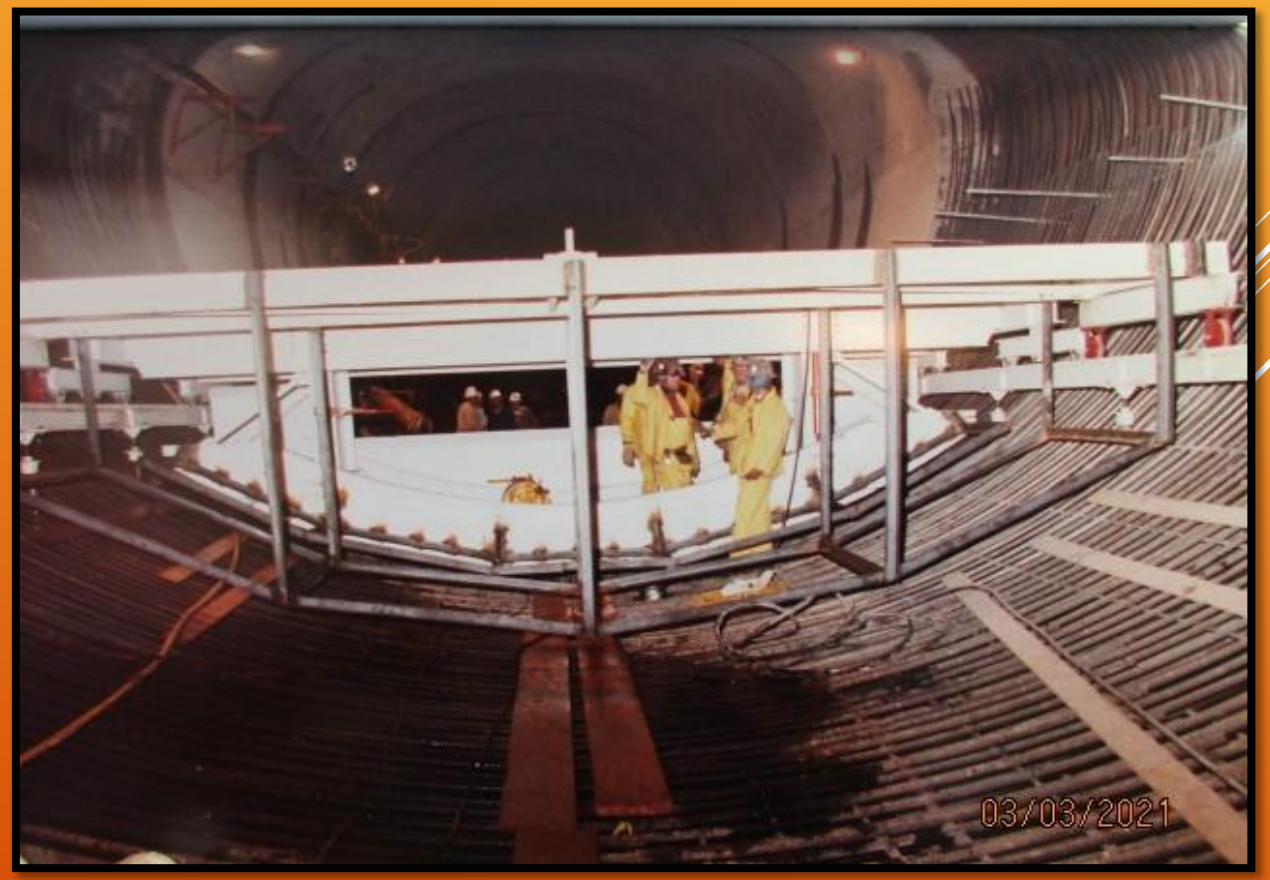
The Hole

Potential Failure Mode = The Christmas Tree meets the Hole meets the Lake. Resulting at a minimum of a drained Lake Powell.

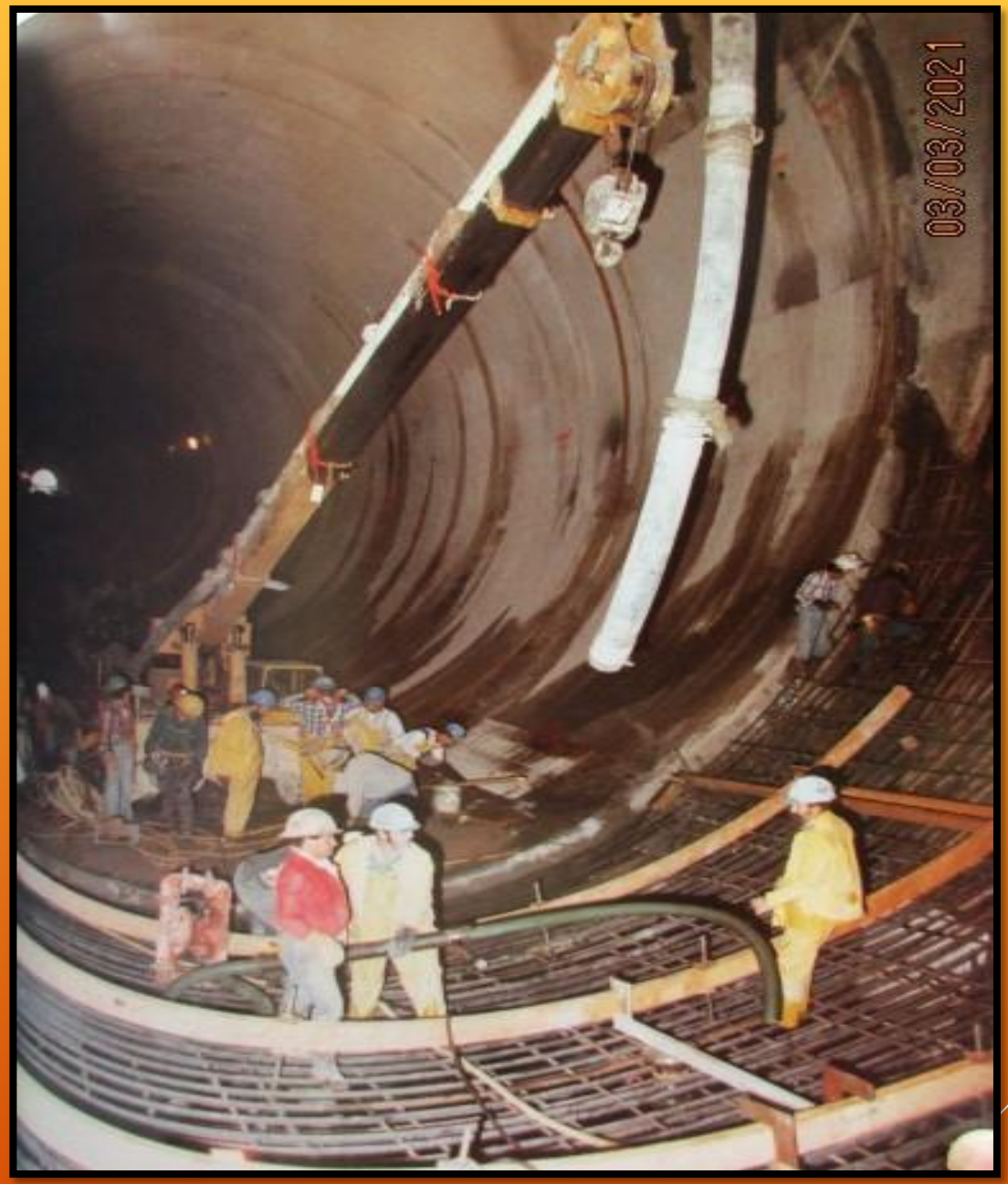


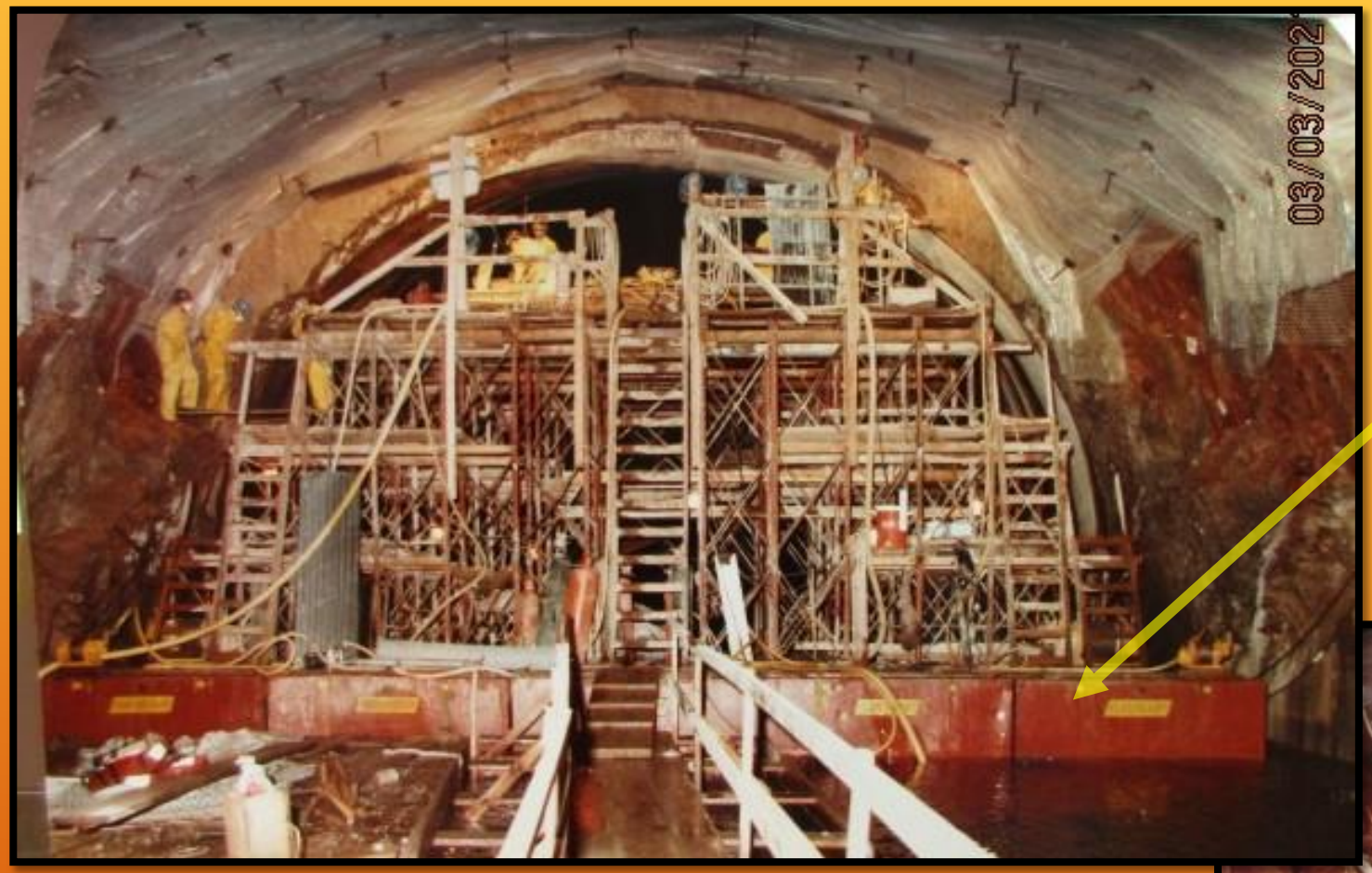
Working conditions for the men was miserable – cold – wet – and dark. Note the temporary structure built overhead to keep the seepage water away from the men and work area.

Floor Repairs. Different screeds required for different areas

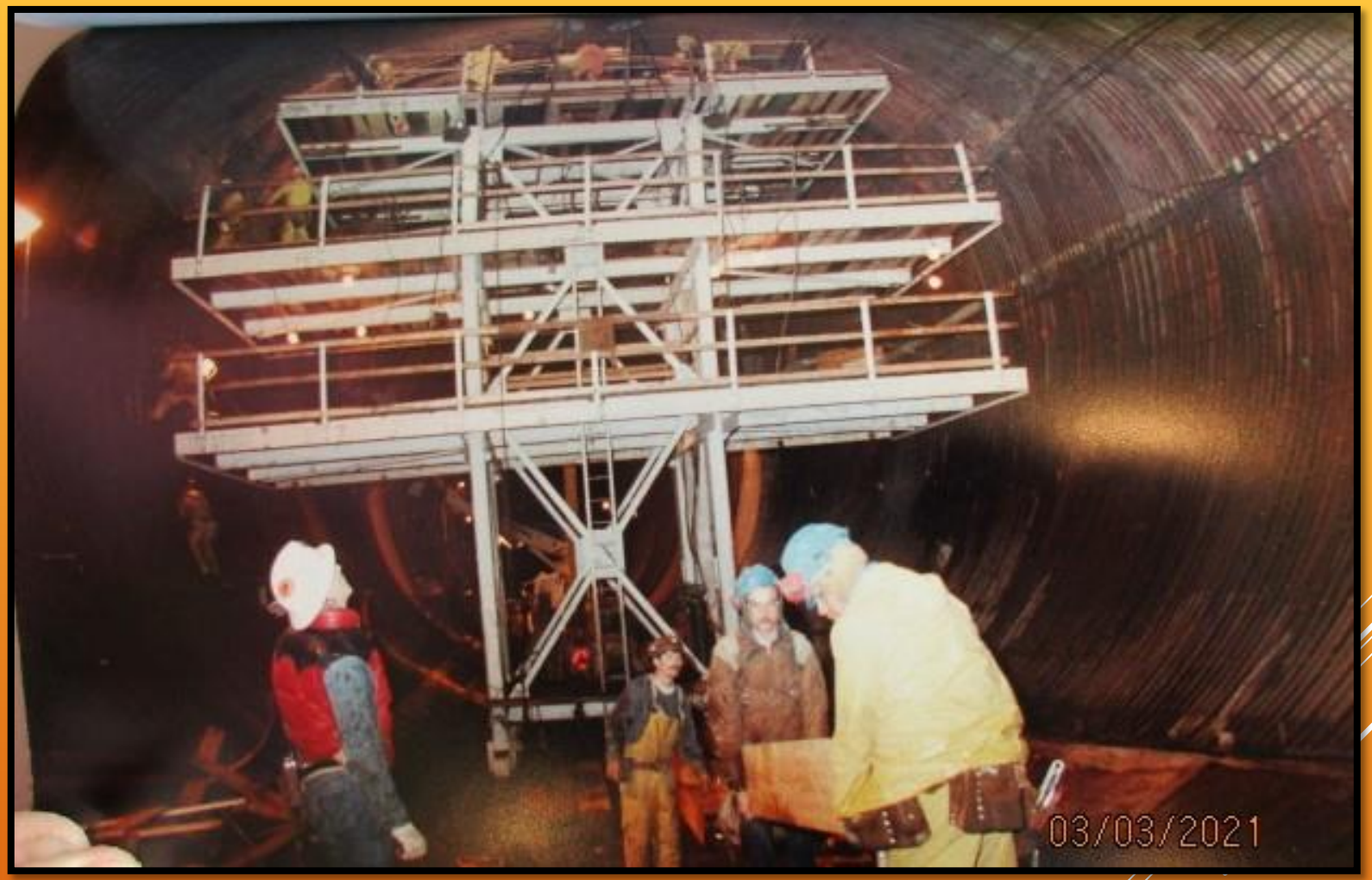


Due to the height limitations of the tunnel a traditional concrete pump would not work so they attached a slick line to a crane boom for concrete delivery.



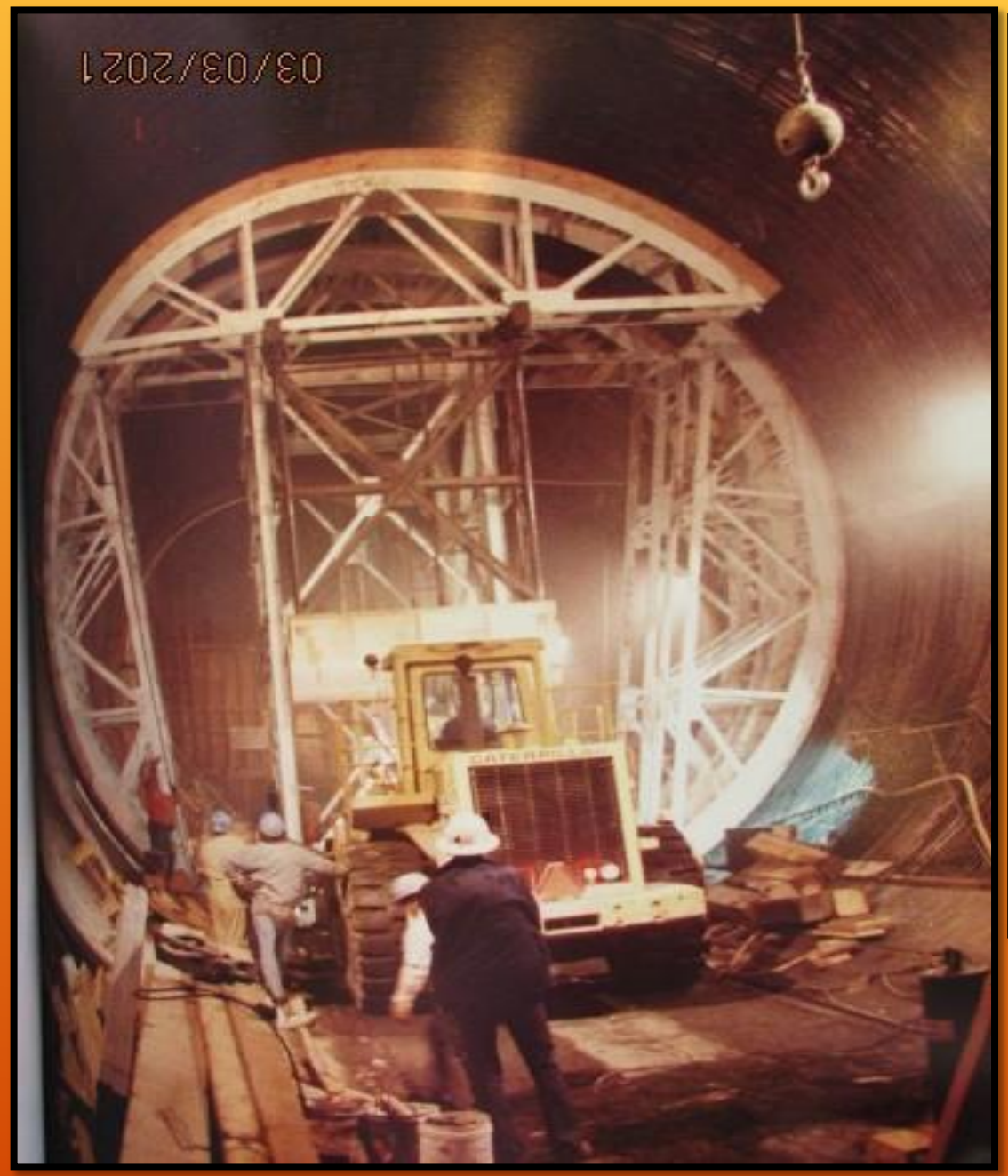


Formwork and supporting falsework on floating barges



This is known as the USBR's "Canary Rebar". If a Canary can get get through it you need to add MORE bar!

Custom Built Formwork

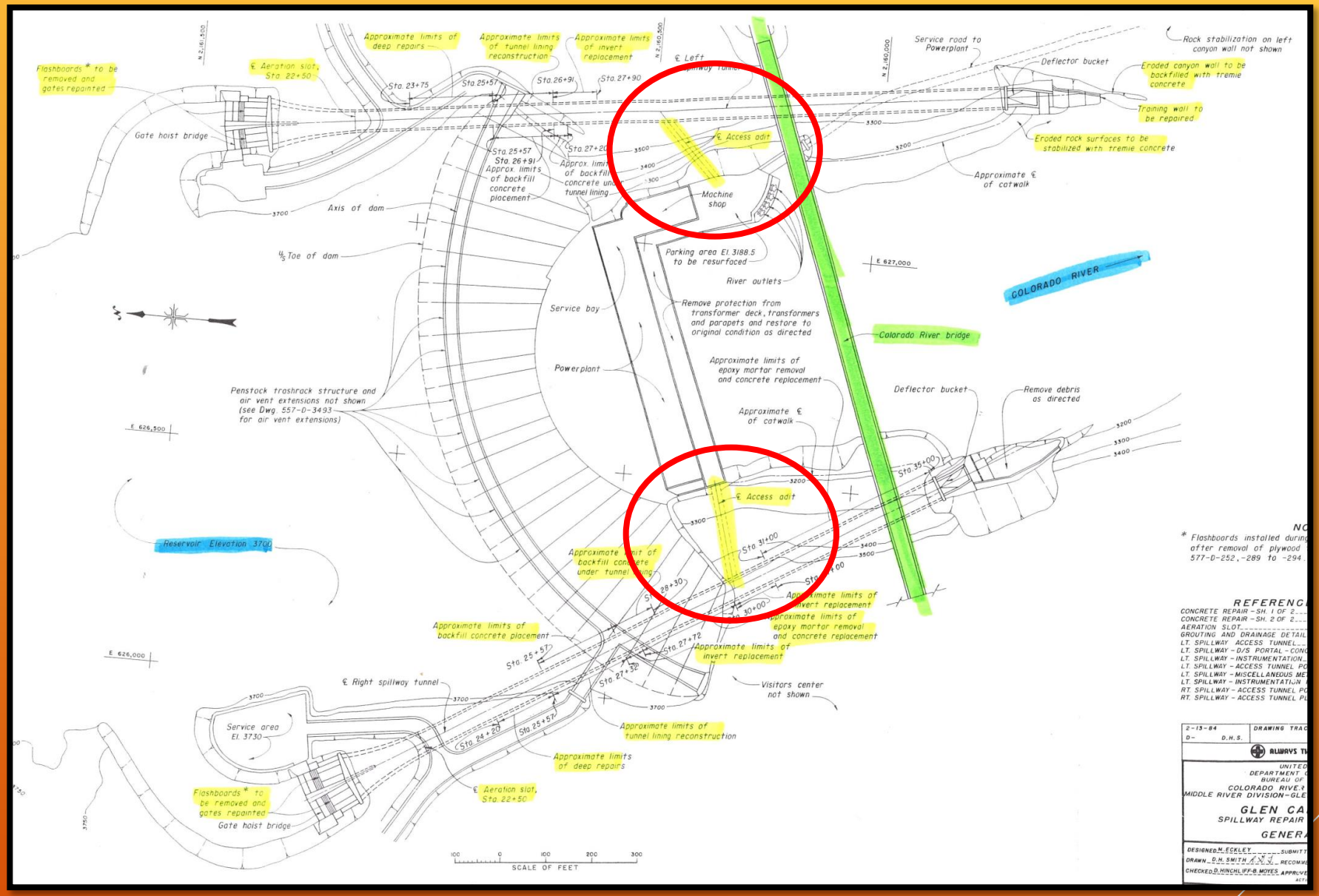


The tunnel height is equal to a four story office building

A Finished Tunnel Section

INTERMISSION

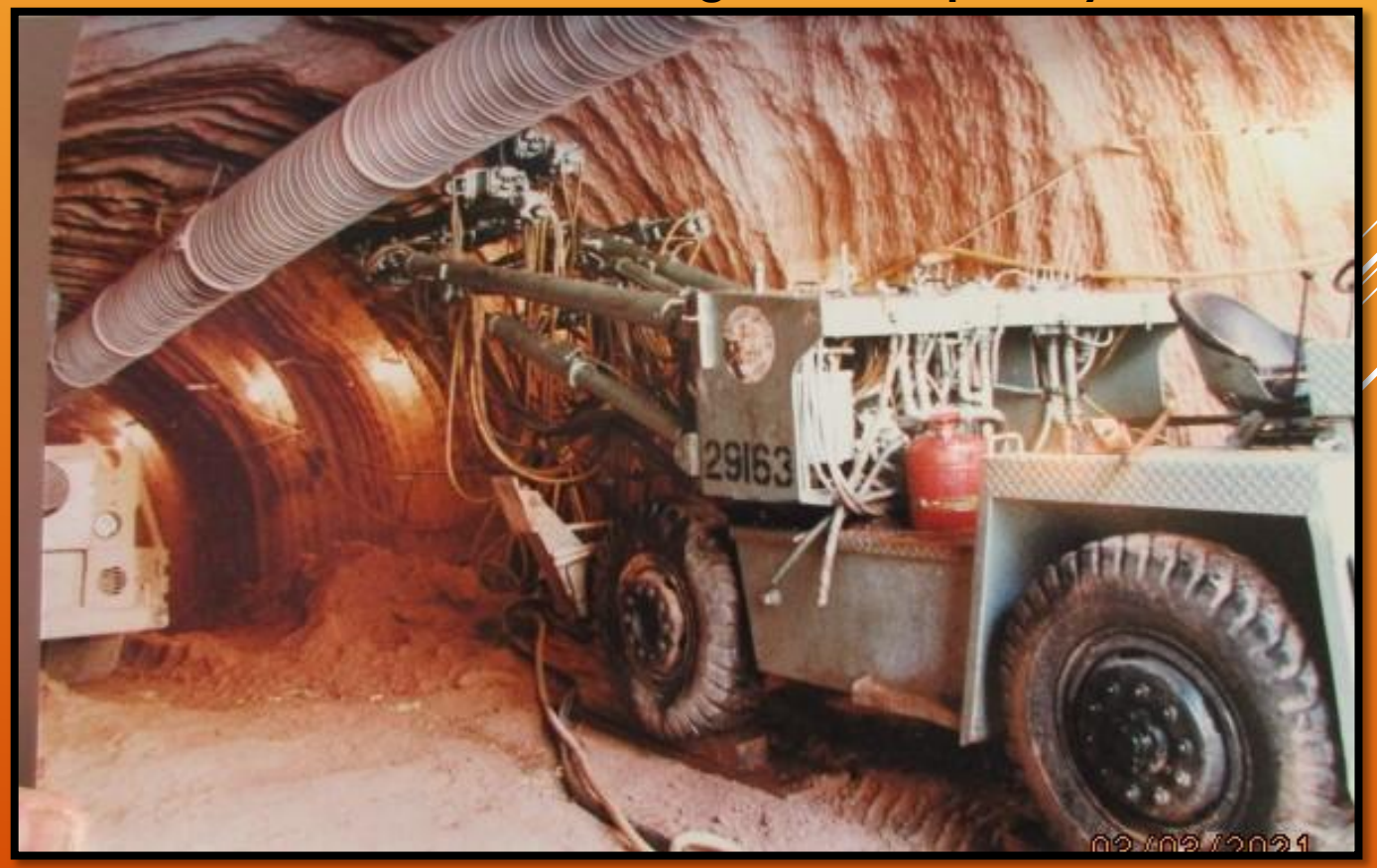
Construction Access

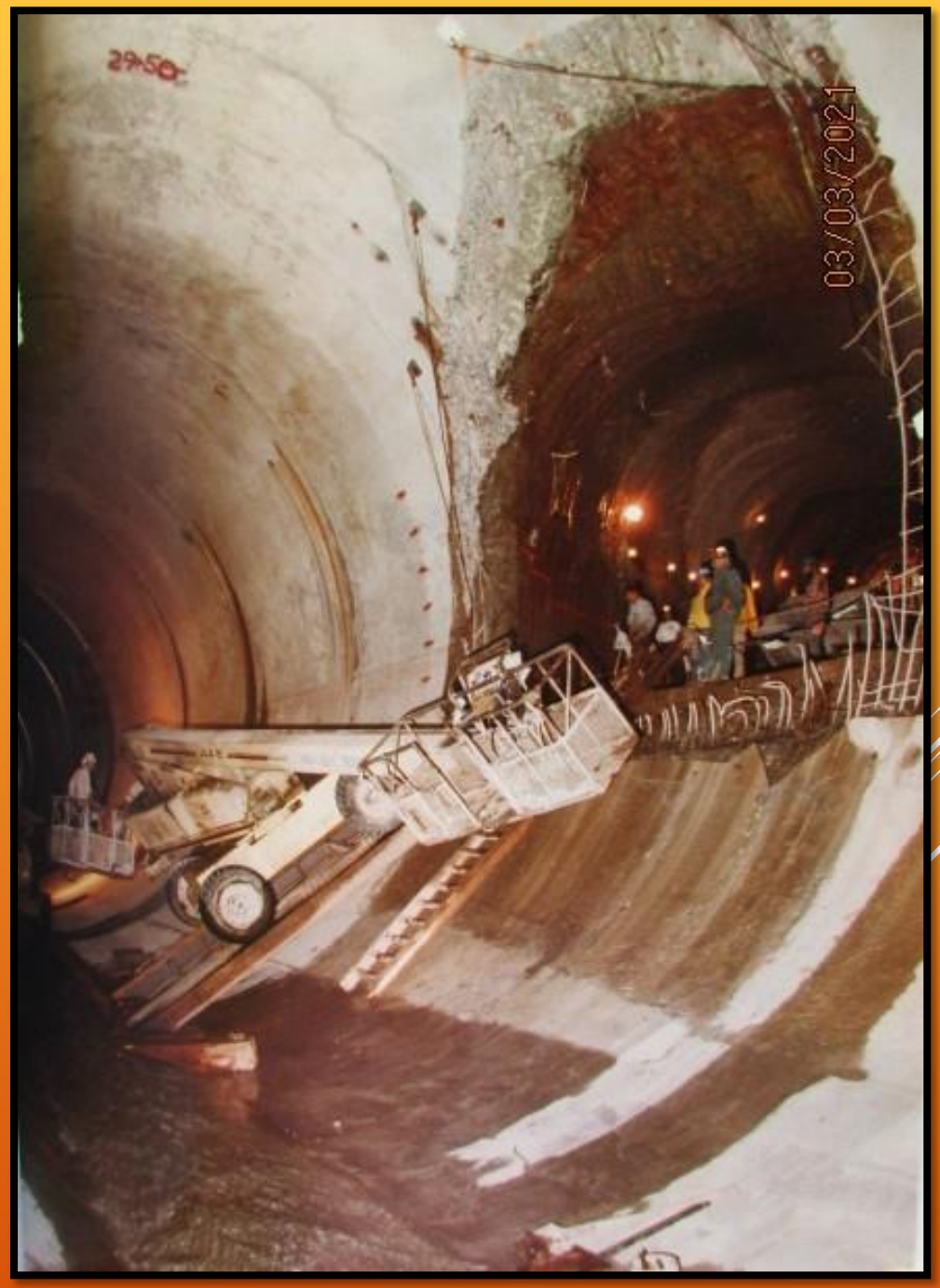


New Access Adits

A Roadheader was used to drive the new Access Adits through the Navajo Sandstone. Note that the 1983 rental cost for this machine was $35,000 per month!

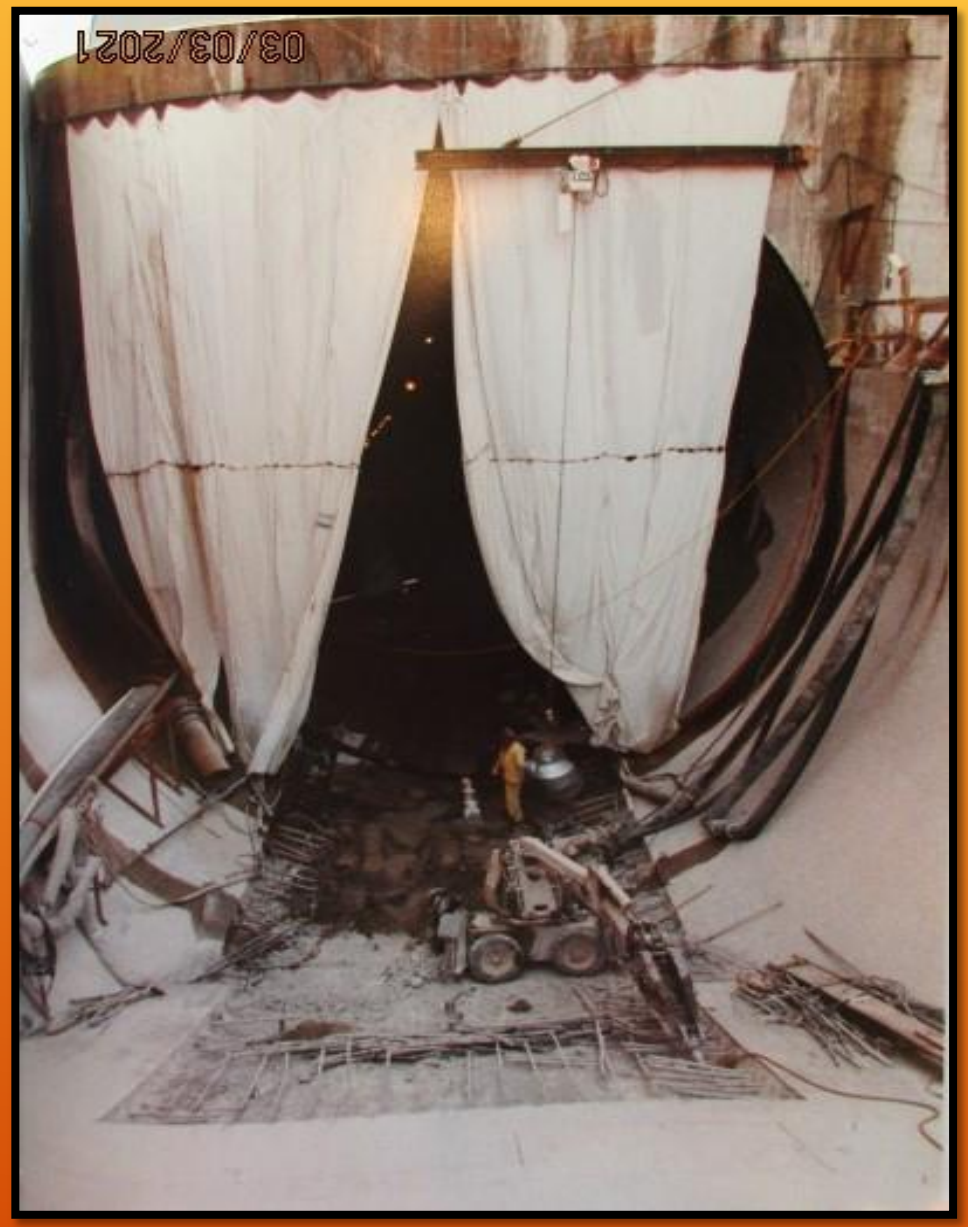
When the adits reached the tunnel the concrete was too tough for the roadheader and a drill jumbo was used to drill and blast the tunnel lining into the spillway.





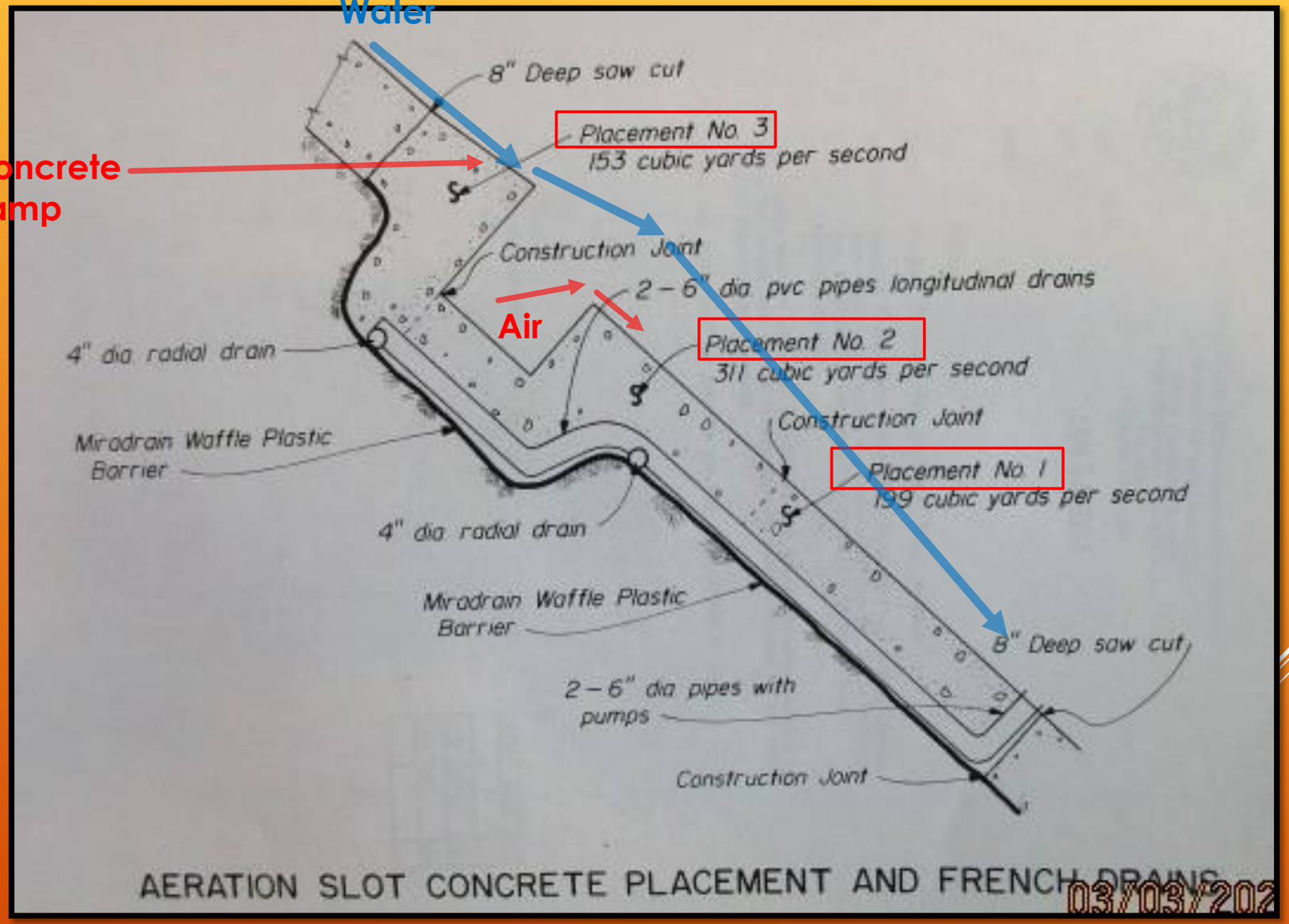
Removing the gravel ramp and equipment at the end of the project.

Closing off the access adits at the end of the project.



Curtains were initially used to slow the wind traveling up the tunnel during the winter, but they were soon replaced with a wooded structure.

THE Aeration Slot


Water
Concrete Ramp
8" Deep saw cut
Placement No. 3
153 cubic yards per second
Construction Joint
2 – 6" dia pvc pipes longitudinal drains
Air
4" dia radial drain
Placement No. 2
311 cubic yards per second
Construction Joint
Mirodrain Waffle Plastic Barrier
Placement No. 1
199 cubic yards per second
4" dia radial drain
Mirodrain Waffle Plastic Barrier
8" Deep saw cut
2 – 6" dia pipes with pumps
Construction Joint
AERATION SLOT CONCRETE PLACEMENT AND FRENCH DRAINS
03/03/202

Air enters here and goes under the water here.

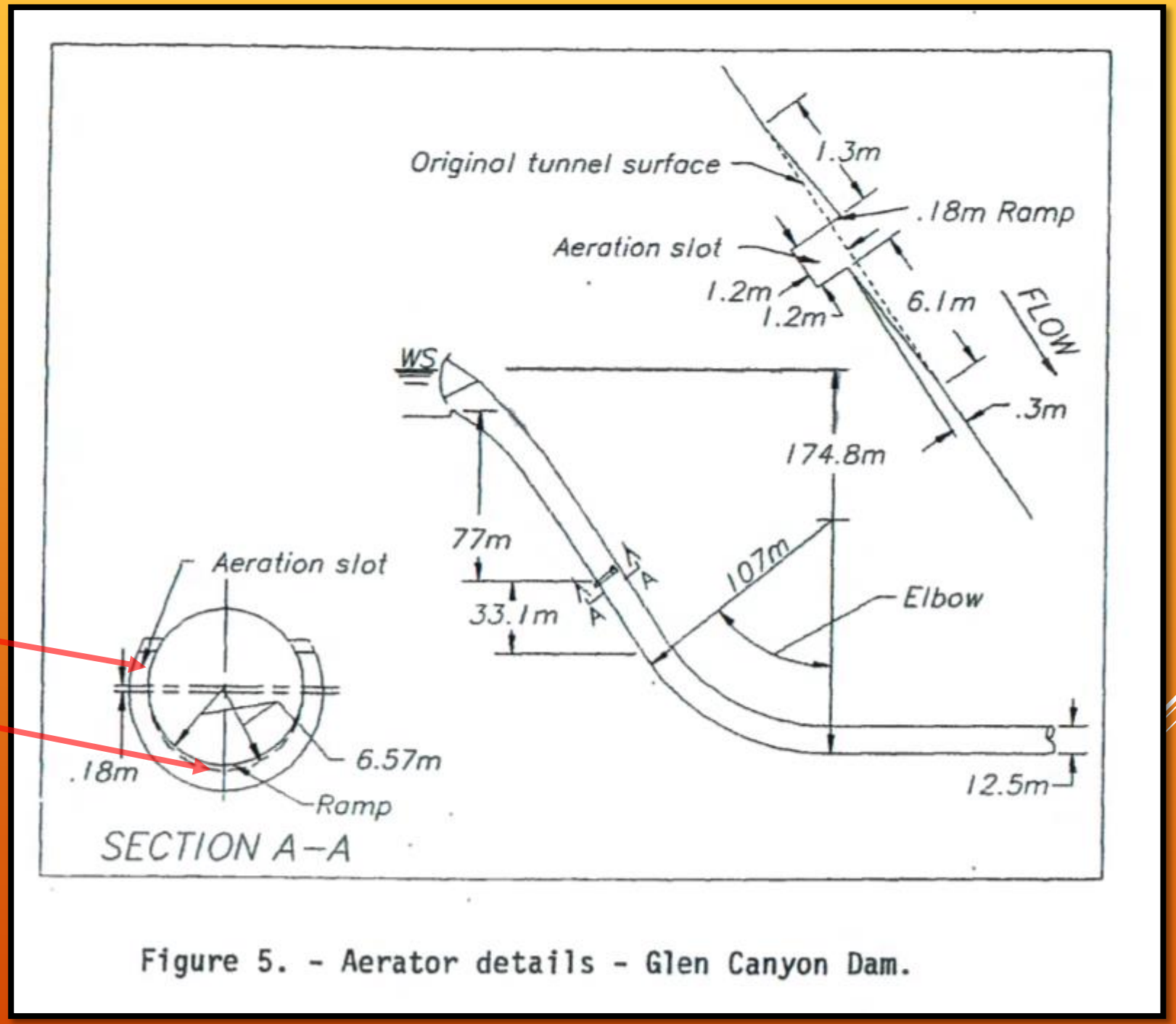


Figure 5. - Aerator details - Glen Canyon Dam.

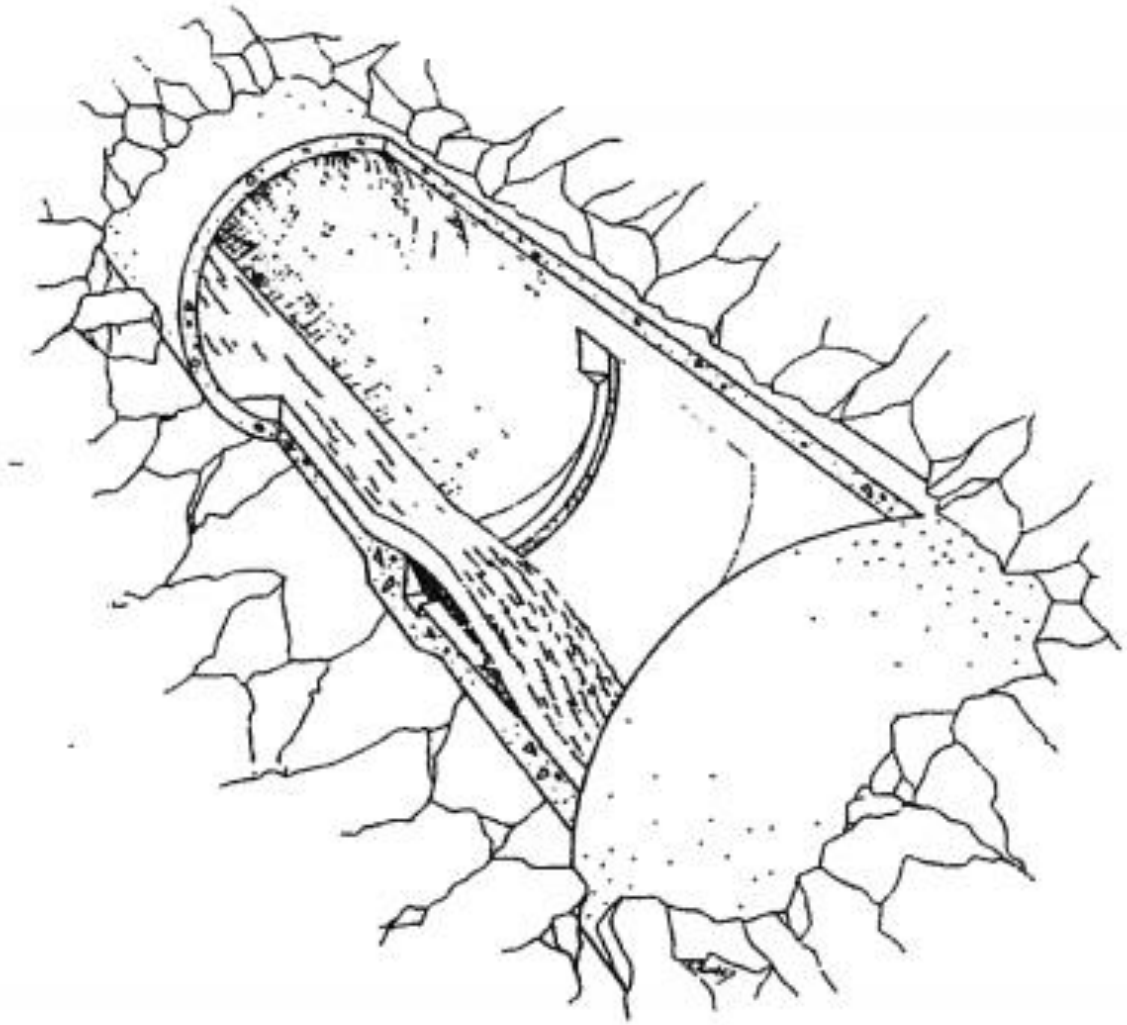
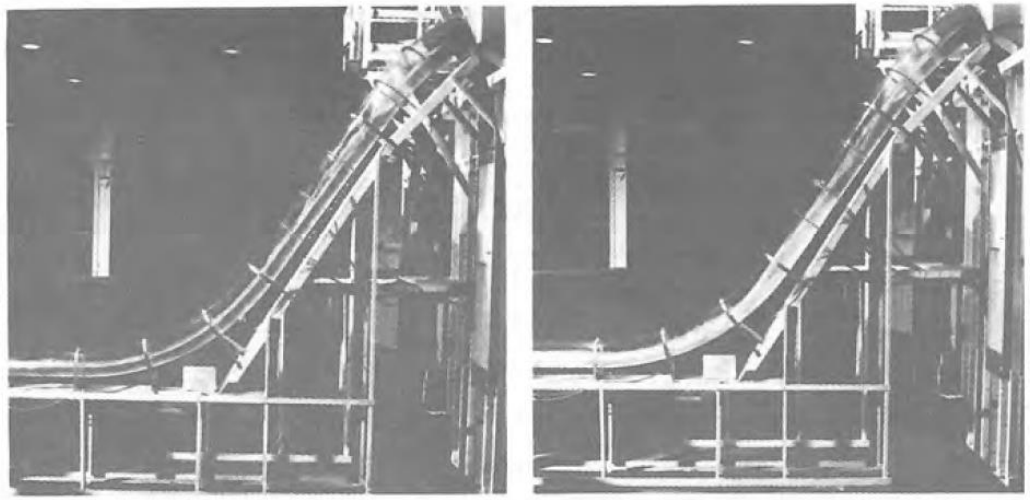


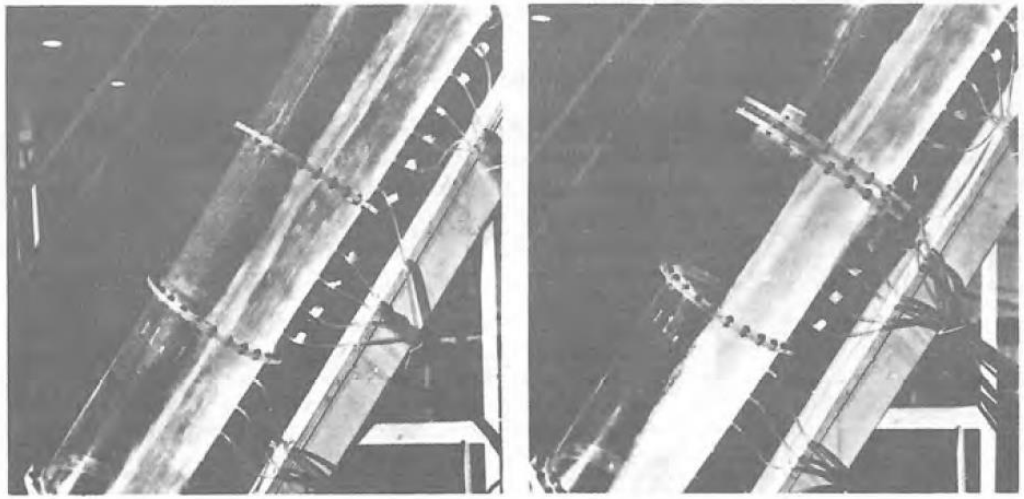
Figure 1. - Schematic diagram of Glen Canyon spillway aerator.

Model Testing at the USBR's Hydraulics Lab in Denver.



a. Without aeration slot b. With aeration slot

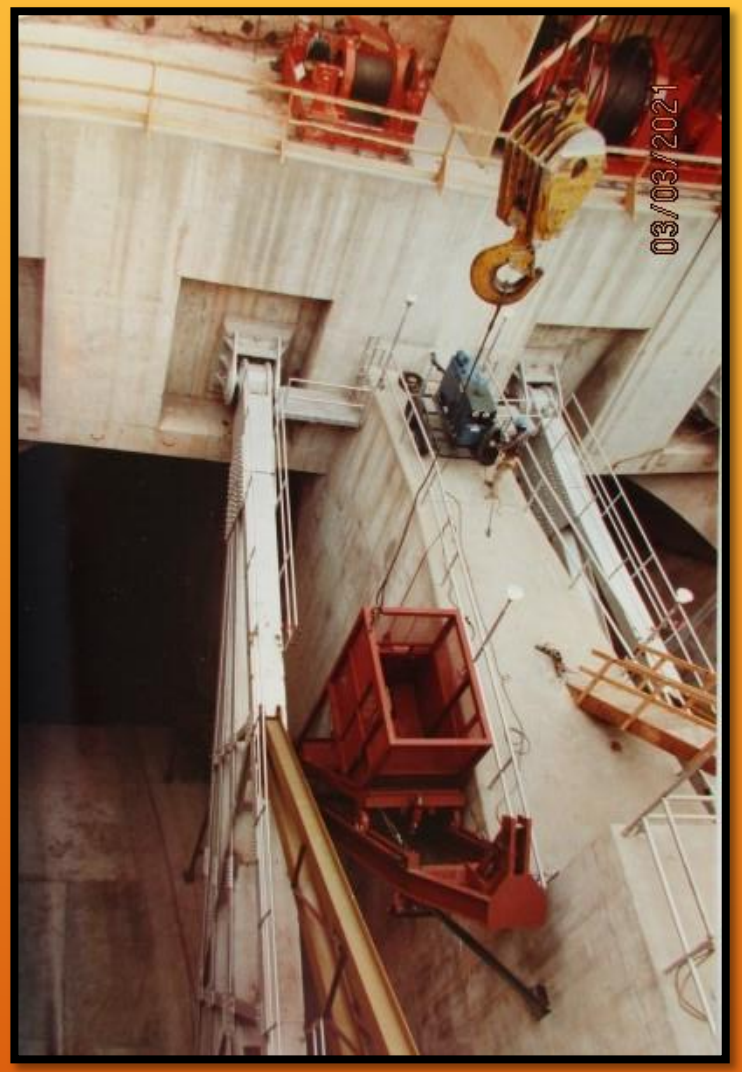
Figure 4 Glen Canyon left spillway tunnel, Q = 100 000 ft^3/s (2830 m^3/s).



a. Without aeration slot b. With aeration slot

Figure 5 Sloping portion of left spillway tunnel (55° angle). Q = 75 000 ft^3/s (2120 m^3/s).

Early Aeration slot work platform – ultimately not used.



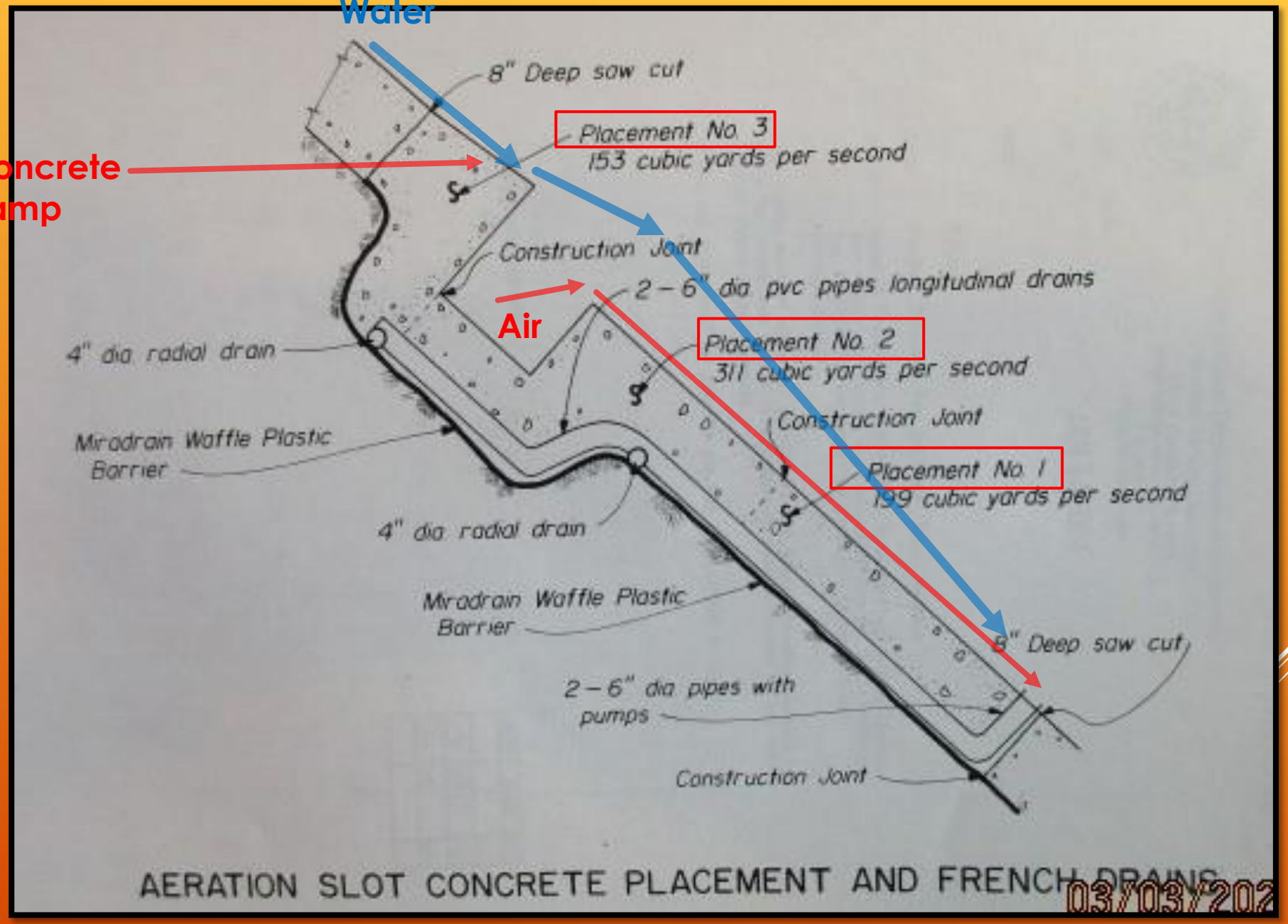
Top and bottom views of man access skip.

Using Jack-Leg drills for blast holes at the aeration slot.

Loading the blast holes for a shot.

Formwork for placement #1.

Slot rebar – note how vertical the shaft is.


Water
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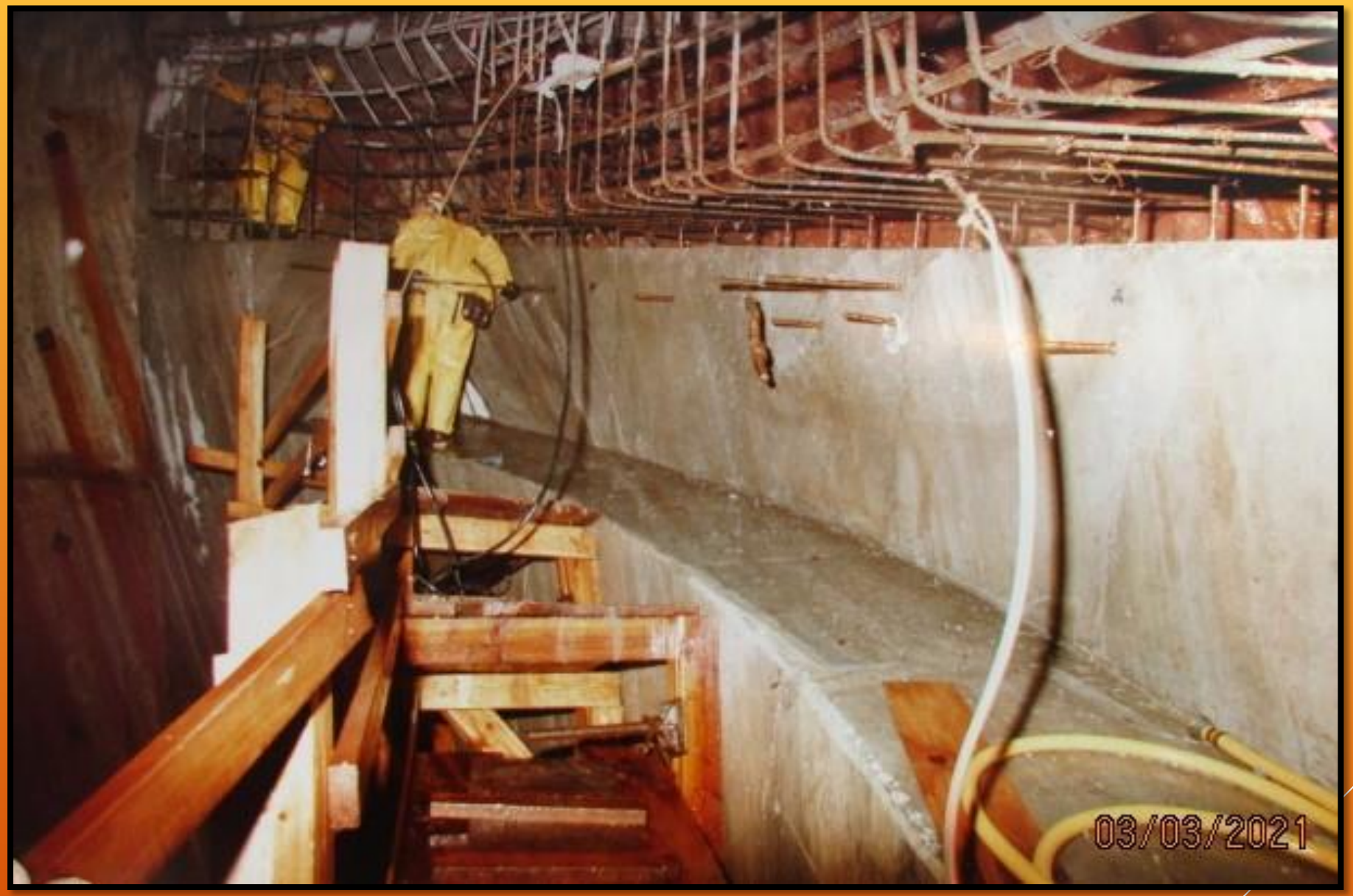
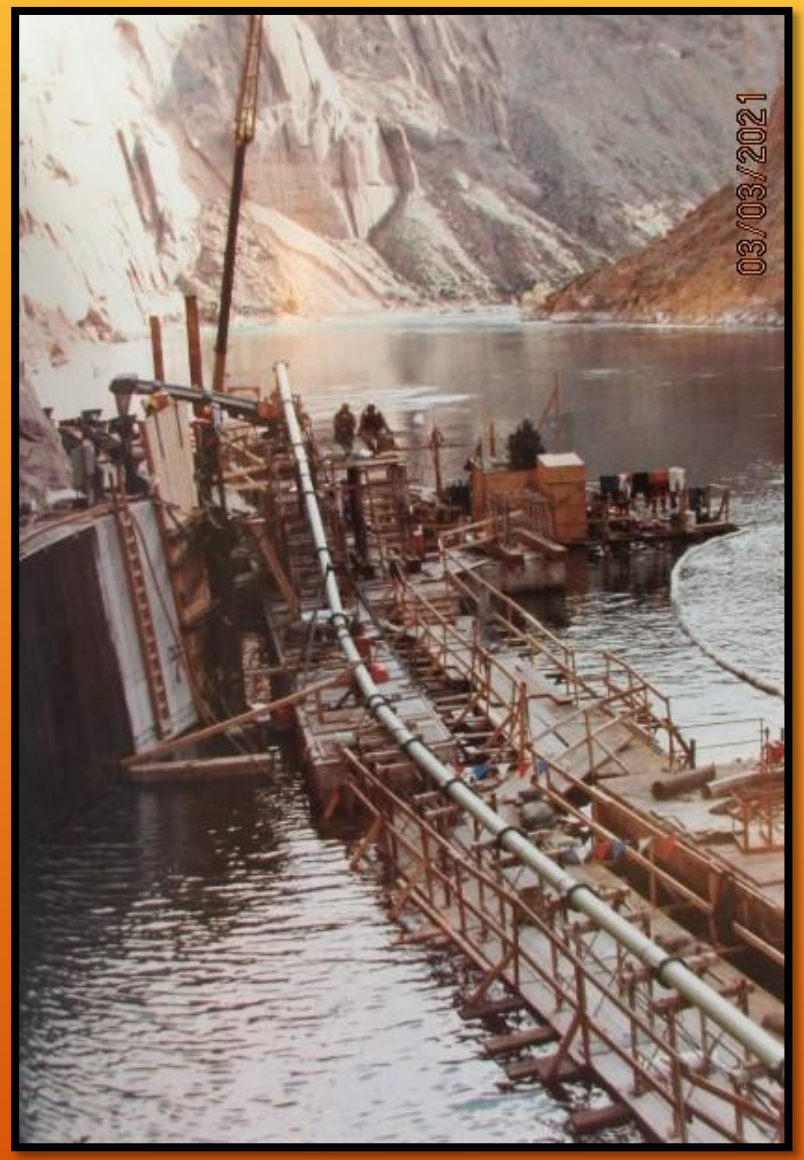
Construction Joint
AERATION SLOT CONCRETE PLACEMENT AND FRENCH DRAINS
03/03/202

Prepping for placement #2

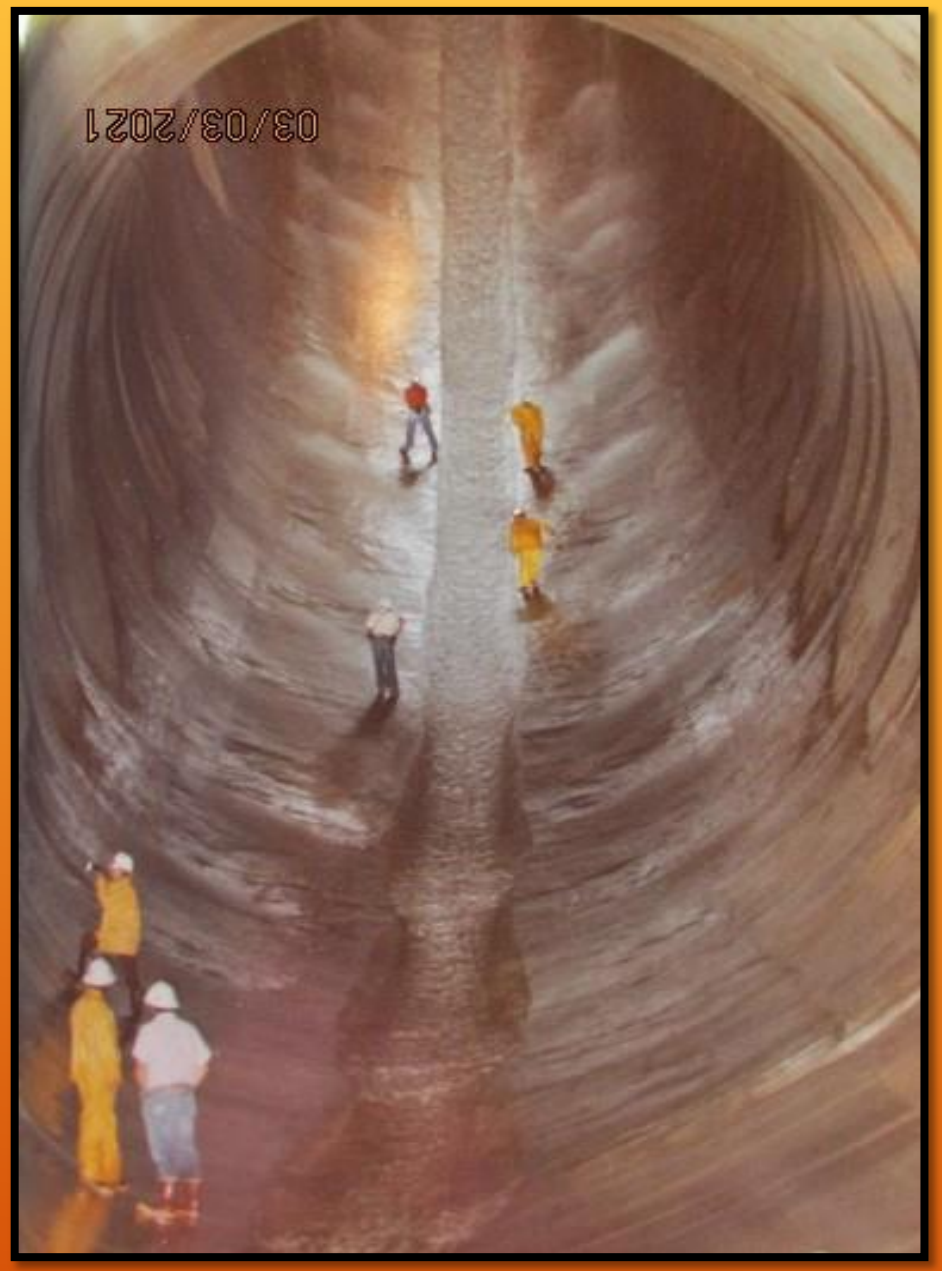


Completed placement #2.

The Contractor's access skip about to cross over the slot on ramps.

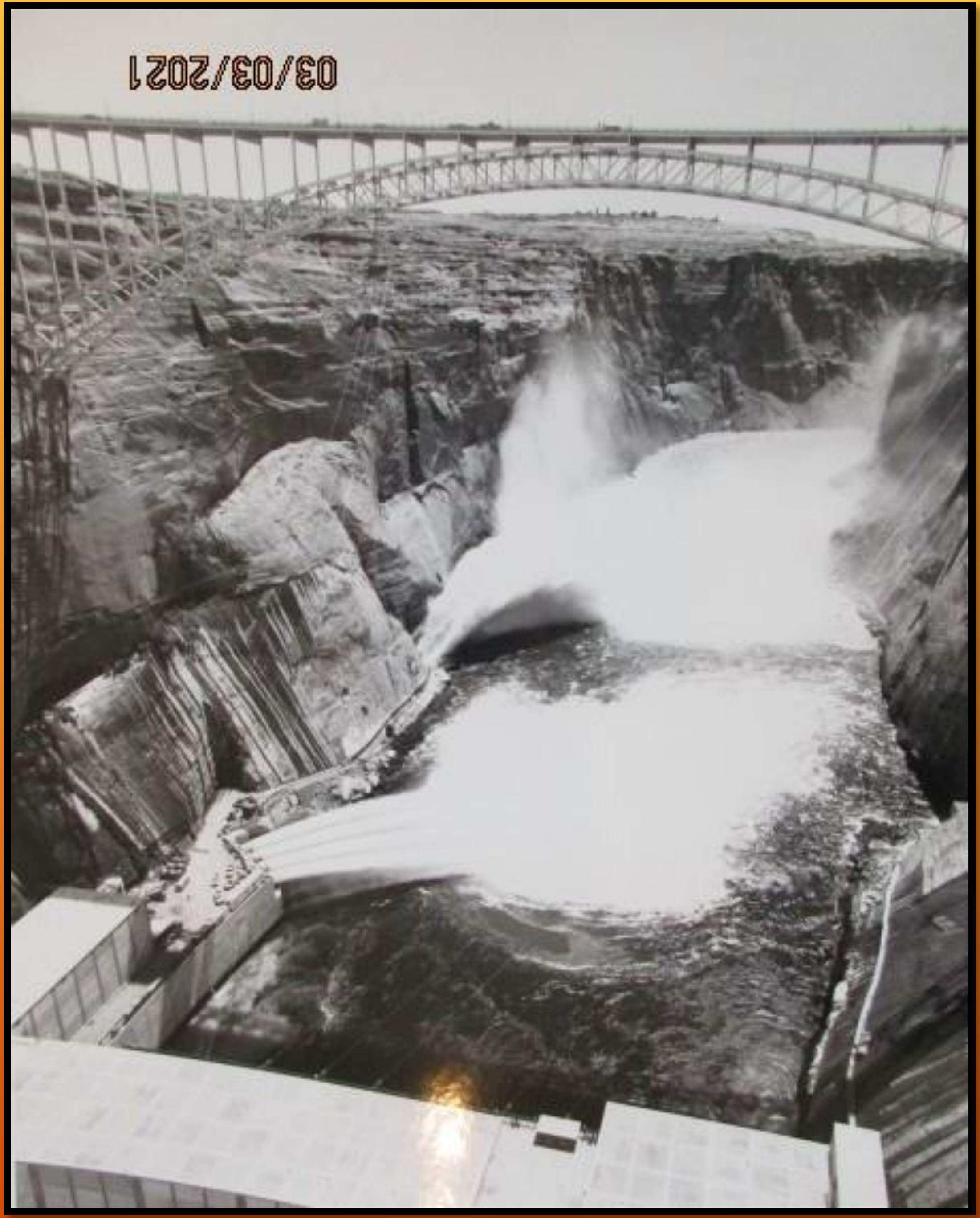


Concrete repairs at the downstream portal due to erosion.



Completed Repairs

Testing up to 50,000 cfs.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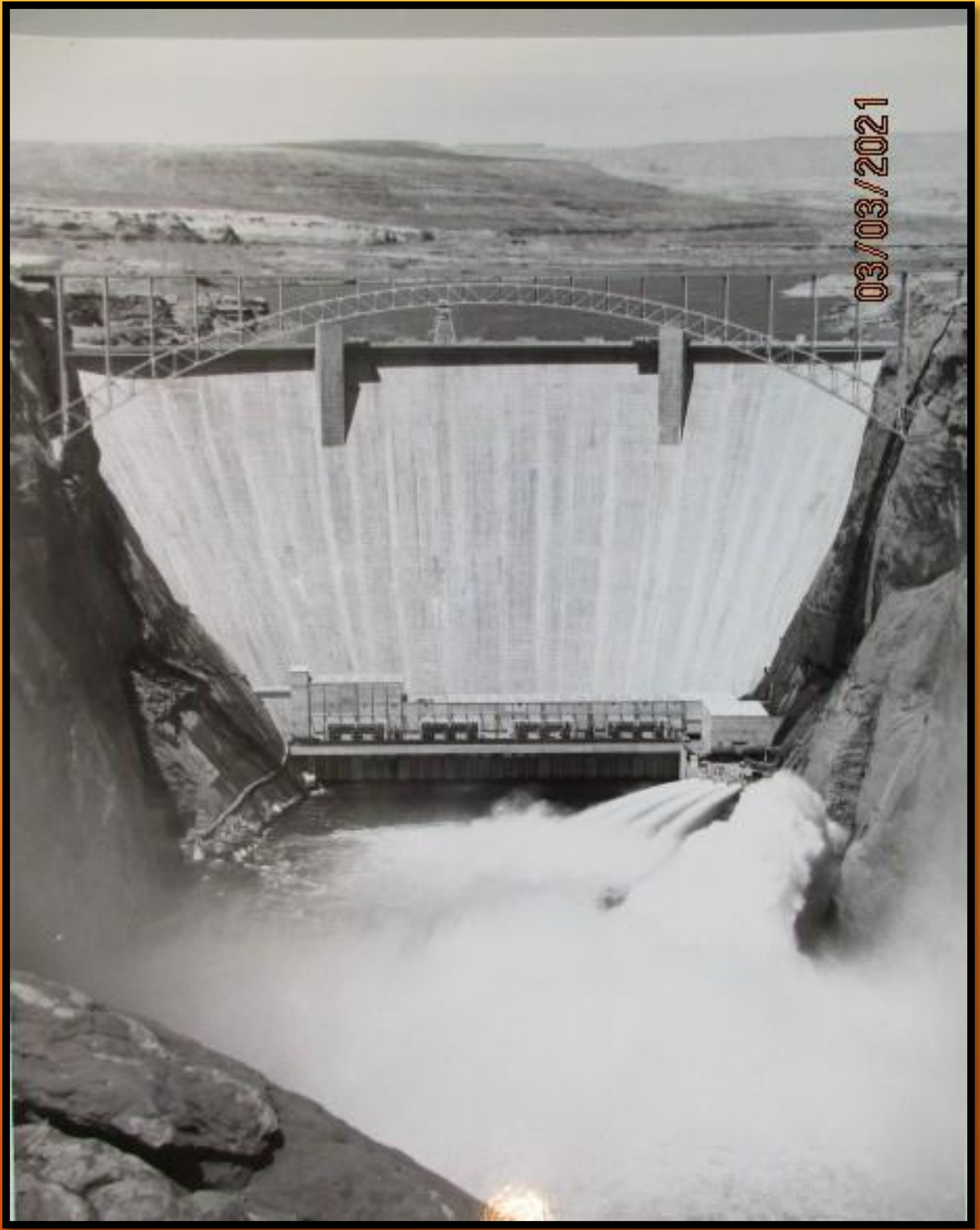
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