PAP-784

FLAMING GORGE RIVER OUTLET PIPE FAILURE ROOT CAUSE ANALYSIS

FLAMING GORGE DAM
FLAMING GORGE FIELD DIVISION
COLORADO RIVER STORAGE PROJECT
UPPER COLORADO REGION

Hydroelectric Research and Technical Services Group
Technical Service Center

U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

August 1997

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural resources. This includes fostering wise use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. Administration.

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DATE	PEER REVIEWER(S)	CODE
	Signature	
	Printed Name	
	Signature	
	Printed Name	
Author initials BM	PEER REVIEW NOT REQUIRED	

Report was peer reviewed

D-8450
PRJ-12.00

AUG 26 1997

MEMORANDUM

To: Regional Director, Salt Lake City UT
Attn: UC-100

From: Bert Milano
Manager, Hydroelectric Research and Technical Services Group

Subject: Root Cause Analysis - Flaming Gorge River Outlet Pipe Failure

Attached are three copies of our root cause analysis report for the Flaming Gorge river outlet pipe failure which occurred on June 21, 1997. Included are an analysis of the event, recommendations specifically for Flaming Gorge, and recommendations for the generic implications for other similar Reclamation facilities.

This report is specifically focused on the mechanical, structural, and electrical aspects of the rupture and the ensuing events leading to river flow reduction and loss of power generation. Staff that prepared this report are operations and maintenance technical experts from this office. They were on site, investigating the failure within 60 hours of the rupture. The timeliness of their response gives them a unique perspective on the events and the underlying causes.

Please contact me (303-236-5999) at any time to discuss this report.

Bert Milano

Attachments

cc: Commissioner, Washington DC, Attn: W-1000
Regional Director, Salt Lake City UT, Attn: UC-600
Manager, Curecanti Field Division, Montrose CO, Attn: CCI-100
Manager, Glen Canyon Field Division, Page AZ, Attn: GC-100
(with one copy of report to each)

Manager, Flaming Gorge Field Division, Dutch John UT, Attn: FG-100
(with 3 copies of report)

bc: D-1000, D-8000, D-5000 (Smart), D-5400 (Roluti), D-5400 (Boyle), D-5500 (Sandhaus), D-5500 (Krause), D-6600 (Achterberg), D-8200, D-8300, D-8400, D-8410 (Todd), D-8420 (Drake), D-8420 (Arrington), D-8470 (Veesaert), D-8560 (Burgi), D-8560 (Mefford), D-8180 (Johnson), D-8130 (Mares), D-8450 (Milano), D-8450 (Cline), D-8450 (McStraw), D-8450 (Tolen), D-8450 (Osburn), D-8450 (Price), D-8450 (Becker), D-8500
(One copy of report to each)

WBR:WMcStraw:dbp:8/25/97:236-6047 x312
(WP:FLAMEOW.WPD)

FLAMING GORGE RIVER OUTLET PIPE FAILURE ROOT CAUSE ANALYSIS

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Appendices

1.0 EXECUTIVE SUMMARY

Background

In the afternoon and early evening hours of Saturday, June 21, 1997, the Flaming Gorge No. 2 river outlet pipe ruptured between the ring follower gate and the hollow jet valve causing flooding of the powerplant, shutdown of all three generators, and a reduction of river flow. The facility was unattended at the time of the incident and no injuries or deaths resulted. At no time during or after the incident was the dam structure in risk of failure.

The failure was caused by cavitation erosion of the pipe invert directly downstream of the ring follower gate. The cavitation was caused by a flow disruption caused by the ring follower gate drifting in the closed direction.

Damage to outlet pipe No. 2 included a 16 in. x 22 in. piece of one-half-inch plate steel missing from the invert of the outlet pipe (photographs 1-3) and damage to the concrete located beneath the invert. There appeared to be a significant amount of vibration prior to the rupture as evidenced by the spalled concrete located around the circumference of the outlet pipe at the steel pipe-concrete interface (photograph 4). The maximum dimensions of the damaged concrete were about 5.5 feet in the horizontal direction, 3 feet in the vertical direction, and 2 feet 3 inches upstream into the concrete.

Root Cause Analysis Background

Although a section on root cause analysis would normally be relegated to an appendix, the newness of root cause analysis merits special treatment.

Root cause analysis is a systematic approach to find out what is really wrong. Because it involves digging deep, it has a tendency to show the ugly side of an organization. The appeal of root cause analysis is that it can be used to greatly reduce incidents of a serious and/or costly nature from recurring. To compete in a deregulated environment, utilities need to fix it once, fix it right, and make sure the root causes are addressed throughout the organization. Management has long ago adopted the "defense in depth" concept that imposes multiple barriers to prevent certain events from occurring. The number of protective barriers should be proportional to the seriousness of the event. One must consider the cost of barriers versus the cost of the consequences. Root cause analysis brings the "defense in depth" concept to the surface for management to review.

One usually can assume the staff wants to do a good job (unacceptable job performance usually is not an issue). The staff must understand design basics or their perception of the risks will be low and misunderstood. The reason that people make mistakes is that there is not enough understanding. If the staff doesn't understand the root cause of the event(s), then what else don't they understand?

The typical conclusions (or results) of root cause analysis are:

* No assignment of responsibility
* Unclear job duties
* Communications
* Training
* Procedures
* Bad attitudes
* Management expectations

If management sets expectations but never measures them, then it is not going to matter. Many times, performance is said to be unacceptable when the standard has not been previously set or responsibility never assigned.

When procedures or management are the issue, the staff will usually acquiesce easily. However, when performance is the issue, protective flags and conflicting stories begin to cloud the investigation. Further, if crafts people are not following procedures, it is because management is not enforcing them and, of course, one has to ask: Do written procedures even exist? The majority of problems revolve around the lack of written procedures or not following written procedures, even though staff often thinks they are.

There are many root cause analysis methods, the two most common are:

Causal factor analysis: This method is used for multi-faceted problems involving a complex causal factor chain. A causal factor is an action or lack of action that, had it not been there, the event would not have happened.

Barrier analysis: This method is used to identify protective barriers and equipment failures and procedural or administrative problems.

<u>Root Cause Analysis</u>

The primary event in this incident was the failure of the outlet pipe. As a result of the outlet pipe failure, flooding of the ring follower gate house and powerplant occurred. The flooding was the main secondary event of this incident. The main contributing causal factor to the flooding was the inability to immediately close the ring follower gate. The flooding and subsequent damage to other equipment may have been reduced or eliminated had it been possible to immediately close the ring follower gate.

The failure of the pipe can be directly attributed to cavitation damage caused by the ring follower gate drifting partially closed. The root cause analysis procedure calls for continuing to ask why until the "root cause" is found. In this event when we ask why did the pipe failure occur, the "why tree" breaks out into three branches. Figure 1 is the causal factor chart for the failure of the pipe.

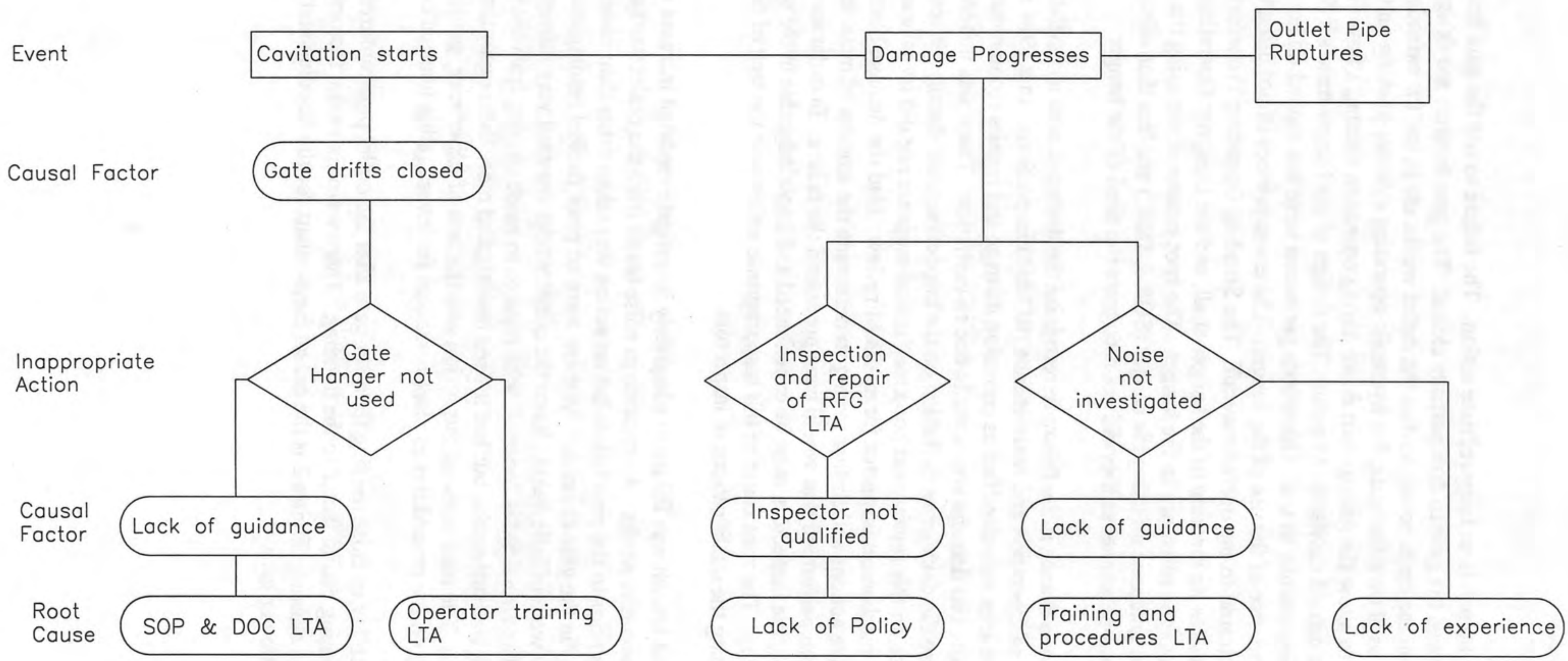

Event
Causal Factor
Inappropriate Action
Causal Factor
Root Cause
Cavitation starts
Damage Progresses
Outlet Pipe Ruptures
Gate drifts closed
Gate Hanger not used
Inspection and repair of RFG LTA
Noise not investigated
Lack of guidance
Inspector not qualified
Lack of guidance
SOP & DOC LTA
Operator training LTA
Lack of Policy
Training and procedures LTA
Lack of experience

Figure 1

The first branch is an inappropriate action. The failure to use the gate hanger on the ring follower gate allowed the gate to drift partially closed. The gate hangers are designed and required to hold the gate in the open position when the outlet works are in use for extended periods. The hanger was not used on either gate, but hydraulic operating cylinder packing on Gate No. 2 had enough leakage to allow the gate to drift down during operation causing a flow disruption in the outlet pipe that caused cavitation to occur. The design of the hanger makes it difficult and awkward, but not impossible, to use. Operations personnel were not trained on how to use the hanger or the importance of the use of the hanger. The consequences of not using the gate hanger were not communicated to the operations staff. The Standing Operating Procedure (SOP) for Flaming Gorge makes no mention of the hanger at all, and the Designer Operating Criteria (DOC) only makes a vague reference to the hanger. The root causes of not using the gate hanger are less than adequate guidance on using the hanger (SOP & DOC) and less than adequate training of operations personnel as they did not recognize the need of the hanger.

The second branch is the failure to recognize the damaged area as cavitation erosion during Review of Operation and Maintenance (RO&M) inspections. In a 1994 RO&M inspection the damaged area was identified as corrosion damage and repairs recommended accordingly. In all probability this damage was actually due to cavitation. There was nobody qualified to correctly recognize the damage as cavitation on the inspection team during this review. The mechanical inspector on this review was not a mechanical engineer nor did he have any other qualifications to act as a mechanical inspector for an O&M review. Had the damage been correctly identified, corrective actions and further testing to determine the amount of metal loss in the pipe shell could have been performed that would have prevented the failure. In order for any review to be effective, the inspectors must be experienced and knowledgeable in the subject they are inspecting. The root cause of this inappropriate action was the lack of directives or policy controlling the qualifications of inspectors.

The third branch was failure to adequately investigate reported increase in noise levels coming from the outlet works. An increase in noise levels from the outlet works was reported by several persons prior to the pipe failure but no action was taken other than obtaining decibel meter readings in the gate chamber. As there were no prior decibel readings to compare these readings to, they were of little value. Since the outlet works are used very infrequently, plant personnel are unfamiliar with what is "normal" with regards to noise coming from the pipes. The noted increase in noise was subjective, but had it been investigated more thoroughly the failure may have been avoided. The root cause of this action was the lack of experience, guidance, procedures, and training on the procedures to plant personnel for investigating unusual conditions.

The inability to close the ring follower gate after the outlet pipe ruptured was identified as a contributing causal factor to the flooding. There were six causal factors identified that prevented the gate closure. Figure 2 is the causal factor chart for the flooding and the inability to close the ring follower gate.

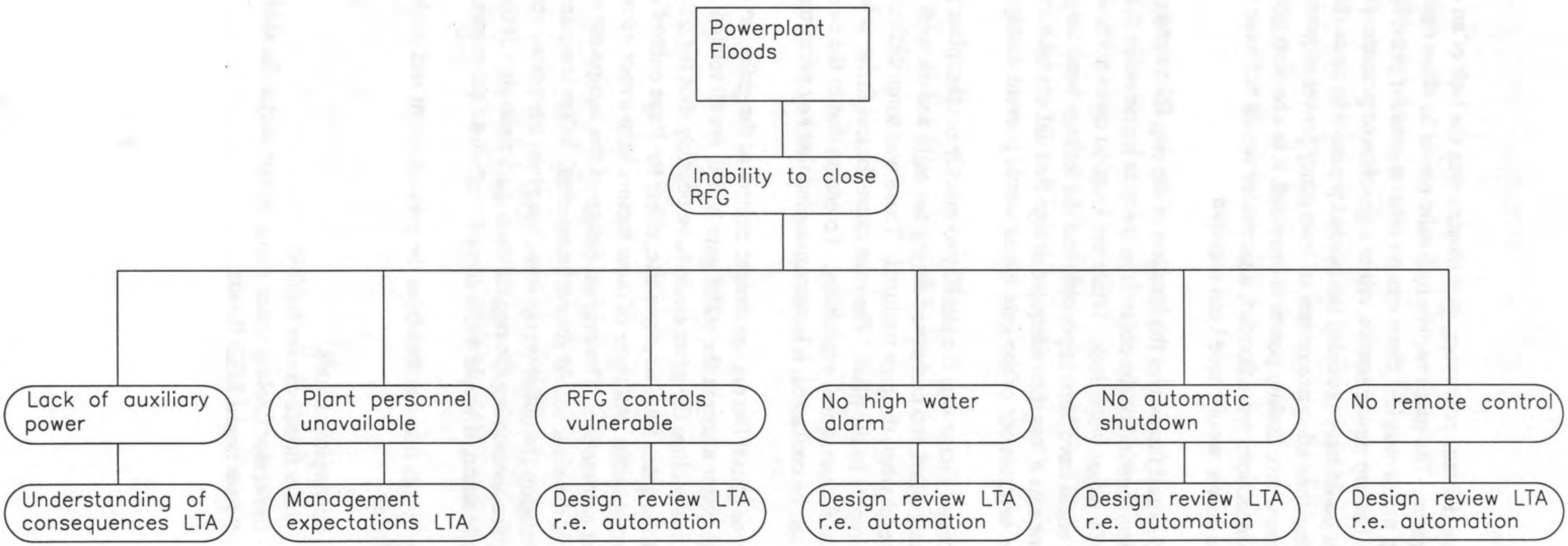

Powerplant Floods
Inability to close RFG
Lack of auxiliary power
Plant personnel unavailable
RFG controls vulnerable
No high water alarm
No automatic shutdown
No remote control
Understanding of consequences LTA
Management expectations LTA
Design review LTA r.e. automation
Design review LTA r.e. automation
Design review LTA r.e. automation
Design review LTA r.e. automation

Figure 2

The first causal factor preventing gate closure was the lack of an auxiliary/backup power supply to operate gates. The gates require hydraulic power to close completely. When electrical power to the pump motor was lost there was no other means for providing hydraulic pressure to the gate cylinder. A backup power source, either a gasoline or propane-powered pump, or a hydraulic accumulator could have provided the needed pressure to close the gates. The root cause of this factor is a less than adequate review of emergency power requirements during the original design. In most cases where backup power is provided, it is a backup generator. In this case where electrical connections were flooded, a generator would not have worked. A nonelectrical source of hydraulic power would have been required.

The second causal factor was the location of the ring follower gate controls in a vulnerable position. The location of the controls in the gate house made them vulnerable to water damage in the event of a major water leak. While the location made accessibility difficult during this incident, it could have been impossible had the leakage been only slightly worse. The root cause of this factor was a less than adequate design that did not take into account this type of failure. Moving the controls out of the gate house would prevent damage and increase accessibility.

The third causal factor was the inability to quickly contact plant personnel. As the plant is remotely controlled and unmanned during the night and on weekends, there was no one available on site to react when the pipe ruptured. There was some difficulty contacting plant personnel to have them report to the plant. The root cause for this factor is less than adequate management expectations for personnel availability. To ensure that in the event of an emergency that personnel can be contacted, it is recommended that key personnel carry pagers at all times.

The last three causal factors, no remote control of the gates, no automatic shutdown of the gates, and no high water alarm in the outlet gate house, are all related. A high water alarm that also acts to automatically close the gates could have possibly shut the gates before flooding occurred. Closure of the gates from a remote site, either the Page control center or another location in the plant, is not possible. All three of these factors have a root cause of a less than adequate design of the plant automation. The original design of this equipment was completed when it was thought that the plant would always be manned. When the plant was automated and converted to remote operation the outlet works were not given adequate consideration. All three factors would require automating the ring follower gate controls. If the controls are moved to a less vulnerable location, it would make sense to automate the controls as well.

Secondary events that resulted from the primary event and made worse by the contributing causal factor include:

a. Powerplant floods
b. Water floods exciter cubicle
c. Generator cooling water pump motor starter flooded
d. Power board MSB floods

The causal factors for the secondary events are discussed in detail in the body of the report.

Public safety concerns are emphasized in the body of the report. It is the opinion of the investigative team that the health and safety of Natural History Association personnel and the touring public were at significant risk in this incident. A change in the practice of public tours is recommended.

2.0 CONCLUSIONS

There were a number of causal factors associated with the rupture of outlet pipe No. 2 that may also be applicable to other Reclamation facilities. It should be noted that Flaming Gorge is considered to be one of the best maintained facilities in Reclamation. The plant personnel are very conscientious in performing their maintenance and diligent in performing testing as evidenced by their compliance with the Emergency Gate Testing Program and the Penstock Inspection and Safety Assessment Program. This scenario raises some issues when one takes into consideration those facilities where maintenance may possibly be somewhat less than desirable. It is essential that management realize that thorough inspection and testing by qualified personnel is required to ensure the reliability of mechanical equipment that is in most cases well over 50 years old at most Reclamation facilities.

In many ways, Reclamation was fortunate that the effects of the rupture of the Flaming Gorge outlet tube were not more damaging. Had the hole in the outlet pipe been larger or if the hole had not been on the bottom of the pipe, the eduction type draining of the gate chamber and control house would not have occurred. Closure of the ring follower gates would have been even more difficult if not impossible. Implementation of the recommendations herein will help eliminate the need to rely on "luck" in the future.

Also, it cannot be overemphasized that the safety of the public and the tour guide was very much in jeopardy in this event. Again, "luck" played a part in keeping people from being injured or killed. We must not rely on "luck". Closing the tour route into the lower elevations is a prudent step in ensuring that the public safety is maintained.

3.0 DESCRIPTION OF EVENTS

3.1 Investigation

The investigation associated with this report started on June 24, 1997, with investigative team members on site at Flaming Gorge. Sources of information included:

Personal interviews with Reclamation staff and Natural History Association personnel
Written statements from key personnel
Sequence of Events Recorder (SER) Output
SCADA Output
Forebay / Tailbay Level Monitor Output
Flaming Gorge Operators Log
Control Center (Glen Canyon) Operators Log
Standing Operating Procedure (SOP)
Technical Record of Design and Construction
Metallurgist Report
Structural Damage Report
Emergency Notification System Plan
Maintenance Records
Mechanical Maintenance Review Reports
RO&M Review Reports
Tour Guide Records
Personal Inspection of Equipment and Facility

3.2 Conditions Prior to Incident

In the morning of Monday, June 16, 1997, both No. 1 and No. 2 river outlet tubes were opened to augment flow through the generator turbines to provide reservoir storage capacity for inflow due to spring runoff. The outlets works are used normally when turbines are out of service or when sufficient releases can't be made through the turbines alone.

Prior to the incident on June 21, conditions were as follows:

Reservoir Water Elevation:	6032.36 @ 17:00 6032.38 @ 18:00
Tailbay Water Elevation:	5604.70 @ 17:00 5604.71 @ 18:00
Tailbay Water Temperature:	approx. 53 degrees F (calculated average from penstock water temps)

River Elevation (monitored
approx. ½ mile downstream) : 14.1 ft above baseline @ 18:00

River Temperature: (Tracked by Utah not BOR)

Spillway Flow: None

No. 1 River Outlet Tube Flow: approx. 2000 cfs. (73%)
No. 2 River Outlet Tube Flow: approx. 2000 cfs. (73%)
Total Spillway and River Outlet Flow: 4152 cfs. (per Glen Canyon Water Report)

Generator / Turbine No. 1
Megawatts: 45
Megavars: +14

Generator / Turbine No. 2
Megawatts: 45
Megavars: +13

Generator / Turbine No. 3
Megawatts: 46
Megavars: +10

Total Generator / Turbine:
Megawatts: 134
Megavars: + 37
Flow: 4412 cfs. @ 17:00
4392 cfs. @ 18:00

TOTAL RIVER FLOW: 8564 cfs @ 17:00
8544 cfs @ 18:00

The plant was unstaffed at the time the incident began (normal operation) and no visitors were in the plant.

3.3 Sequence of Events

Saturday June 21

Approx. 17:30 No. 2 River Outlet Tube ruptured near elevation 5623.50

Ring Follower Gate (RFG) chamber filled with water and overflowed into RFG control house at floor elevation 5638.50.

RFG control house filled with water to approximately 3 feet above floor level. Water forced its way through the RFG control house roll-up door, damaging the door. Water spilled through the roll-up door and down onto the parking lot between the powerplant and the tailrace.

Water entered the powerplant under the passage door and through the louvers in the passage door connecting the RFG control house to the powerplant. This water flowed down the wall and entered the 480 vac Miscellaneous Power Board - MSB. The power bus in the MSB faulted causing station service substation DRA feeder breaker supplying power to the MSB to trip, thus deenergizing all circuits in the MSB. Power was lost to all circuits supplied from the MSB including power to the ring follower gate controls and the hollow jet valve controls.

Water also flowed from the RFG control house into the "mechanics break room" in the north east corner of the generator floor (elevation 5621.00) via a pipe chase. This room filled to approximately 7 feet above floor level and began flowing through the louver in the door into the powerplant onto the generator floor. The force of the water eventually broke the passage door off the door jamb and forced it approximately 60 feet to the south wall of the powerplant. Water exiting from the break room flooded across the generator floor from the east end of the powerplant to the west end of the plant.

Water on the generator floor flowed through floor penetrations around the HVAC ducts and into the motor starters for the Dutch John Water Plant pumps at elevation 5607.25. This disrupted pump operation initiating the first known alarm of the incident.

17:54:07 Water Plant general alarm to SCADA

Water on the generator floor entered embedded conduits under Generators No. 2 and 3 Unit Power Boards M2A and M3A and drained into the generator air cooler motor starters causing failure of these starters. Cooling water flow was disrupted which permitted generator air temperature to rise. Glen Canyon operator tries to call out Flaming Gorge water treatment operator and has no response.

17:59:49.043 Unit 3 Generator Cooling Water Pressure Low
Glen Canyon operator tries to call out Flaming Gorge maintenance staff and has no response.

18:04:19.364 Unit 3 Generator Cooling Air Hot

18:05:16.824 Generator No. 3 Lockout

Water on the generator level also ran through floor penetrations into the tops of the excitation equipment on floor elevation 5607.25. This water damaged excitation control equipment causing exciter misoperation. Water on the generator elevation also ran through floor penetrations in the control room onto equipment in the communication room below. Both battery chargers were destroyed as well as the plant uninterruptible power supply (UPS).

18:06:54.590	Battery Charger No. 1 Failure
18:07:05.369	Battery Charger No. 2 Failure
18:07:18.542	Unit 2 Over / Under Excitation Alarm
18:07:20.776	Battery System Ground Alarm
18:07:34.476	Battery Charger No. 1 Failure
18:09:02.400	Unit 2 Generator Loss of Field
18:09:02.416	Unit 2 Generator Lockout
18:11:37.799	Unit 1 Over/Under Excitation Alarm
18:14	Glen Canyon Control called out Flaming Gorge Power Facilities Supervisor

Water from the generator floor ran down the stairwells at both ends of the plant into lower levels of the plant. Water in the west stairs accumulated in the landing at elevation 5608.50 until it forced its way through the sheetrock into the stairwell and continued on to the penstock gallery and other lower levels. The turbine pit flooded to the top of the wicket gates and the oil storage room at elevation 5592.25 flooded. Water flooded the penstock gallery (floor elevation 5587.25) and triggered the high water alarm at approximately 5587. 58 which automatically shuts down the unit penstock gates.

18:30:38. 367	Penstock Gallery High Water Level Alarm
18:30:44.491	Unit 1 Penstock Gate Start Close
18:30:58.933	Unit 3 Penstock Gate Start Close
18:30:59.071	Unit 2 Penstock Gate Start Close

Loss of water pressure in the penstocks initiates unit lockout, and the resultant loss of flow through the penstocks caused river flow to drop below minimum levels.

18:30:41.212	Unit 1 Penstock Gate Closed
18:32:48.705	River Flow Below Minimum

At this time, flow was as follows:

Powerplant Flow: None
Spillway Flow: None
No. 1 River Outlet Flow: 2000 cfs.
No. 2 River Outlet Flow: 2000 cfs. (Estimated)

Total River Flow: 3466 cfs @ 19:00
2000 cfs @ 20:00

18:32:52.174	UPS stopped operating
19:15	Plant mechanic reported to Glen Canyon water on the generator floor.
20:00 approx.	No. 1 and No. 2 Ring Follower Gate lowered manually by operator to approximately 50-60% open by gravity closure (electrical power not available)
20:10	Report to Glen Canyon that flooding of the RFG control house had been stopped
21:00	Spillway Gates opened to 2.2 ft. (2000 cfs)

Total River Flow: 4000 cfs @ 21:00

Sunday June 22

Electrical power restored to Ring Follower Gate and Hollow Jet Valve control.

00:30	No. 2 Ring Follower Gate and Hollow Jet Valve Closed

At this time, flow was as follows:

Powerplant Flow: None
Spillway Flow: approx. 2000 cfs.
No. 1 River Outlet Flow: 2000 cfs.
No. 2 River Outlet Flow: None
Total River Flow: 3900 cfs. (per operators log)

10:00	Bulkhead Gate installation complete on No. 2 river outlet intake.

Prior to the incident, the generating units were under Supervisory Control from Glen Canyon. River outlet operation is local to Flaming Gorge and is not under Glen Canyon control.

3.4 Summary of Damage

Damage to outlet pipe No. 2 included a 16 in. x 22 in. piece of one-half-inch plate steel missing from the invert of the outlet pipe (photographs 1-3) and damage to the concrete located beneath the invert. There appeared to be a significant amount of vibration prior to the rupture as evidenced by the spalled concrete located around the circumference of the outlet pipe at the steel pipe-concrete interface (photograph 4). The maximum dimensions of the damaged concrete were about 5.5 feet in the horizontal direction, 3 feet in the vertical direction, and 2 feet 3 inches upstream into the concrete. A thorough description and photographs of the concrete damage are described in Dan Mares's (D-8130) travel report dated July 7, 1997, and is included in this document as Appendix B.

Metallurgical analysis shows that the rupture in the steel outlet pipe was initiated by the effects of cavitation damage in conjunction with the combined effects of corrosion and erosion at the location of a welded joint (photographs 5 and 6). Severe cavitation damage appears approximately 6 to 8 inches downstream of the gate slot and continues all the way to the ruptured section. Heavy metal loss was noted in this area on the invert of the outlet pipe. Some of the pits were approximately 1/4 to 3/8-inch deep in some locations. The findings of the metallurgist found the outlet pipe rupture was initiated by cavitation damage which led to corrosion and erosion damage. No material defects were found in the weld metal or the base material. A copy of the metallurgist's report is included in this document as Appendix A.

It is believed that the outlet pipe shell developed a crack between two large cavitation pits located at the welded joint of the steel pipe to the flange that bolts to the body of the ring follower gate (photographs 7 and 8). It appears that the internal pressure in the pipe initially caused the broken piece of the outlet pipe to be forced downward at the upstream end at the location of the crack in the weld. The concrete encasement most likely held the fractured piece in place for a period of time until the internal flow in the pipe forced the upstream end of the broken piece upwards. The force of the internal flow then caused a section of the pipe to bend upward, then pivot about the axis of the bend, and break at a location near the concrete-to-steel pipe interface. The broken piece then traveled down the outlet pipe and was discharged through the stay vanes located in the lower left-hand quadrant of the hollow jet valve. This was evidenced by the damage to the coal tar epoxy coating throughout the outlet pipe and by the scrape marks in the hollow jet valve body (photographs 9 and 10).

The cavitation damage was most likely induced by an offset between the leaf of the ring follower gate and gate body. An offset of the ring follower gate combined with an average flow velocity of approximately 84 feet per second in the outlet pipe was the probable cause of the cavitation damage. Plant personnel indicated that the ring follower gate for outlet No. 2 had a tendency to drift downward, sometimes as much as 3-4 inches while in the full open position due to oil leakage in the hydraulic operating system. Subsequent testing after the outlet pipe failure indicated that the gate would drift approximately 1 inch per day. The hoist cylinder packing for ring follower gate No. 2 has a substantial amount of leakage past the packing and was scheduled for overhaul for the fall of this year (photograph 11). The gates are equipped with manual gate hangers to hold the ring follower gates open in the event of leakage such as this. The manual gate hangers were not engaged on either gate at the time of the outlet pipe failure. Failure to use the gate hanger is one of the primary factors leading to the pipe failure.

The expansion joint on outlet pipe No. 2 was missing approximately 7 bolts on the downstream side of the expansion joint and several of the nuts on the remaining bolts had backed off the threads and were loose (photographs12 and 13). Several of the nuts on the upstream side of the expansion joint were also loose. The water leaking from the ruptured area of the outlet pipe tore off the ladder attached to the expansion joint (photograph 14). It is believed that the force of this action forced the expansion joint outer sleeve to move in the downstream direction until the metal stop was pushed against the inner sleeve located on the downstream side of the expansion joint (photograph 15). The expansion joint for outlet pipe No. 1 was inspected after the ring follower gate for outlet No. 2 was closed and was noted to be leaking. The bolts were tightened and the leakage was eliminated.

Flooding into the plant damaged a 480 vac distribution board which supplies electrical power to both the ring follower gate control and the hollow jet valves making them electrically inoperable (photograph 16). Flooding inside the gate house damaged the roll-up door of the gate control house (photographs 17 and 18). The water was approximately 3 feet deep inside the gate house at this time (photograph 19). The water in the control house entered the powerplant through a pipe chase that led to the break room and also through the door which provides access to the powerplant from the gate house (photographs 20 and 21). The water level in the break room was approximately 7 feet deep and caused the break room door to be damaged and blown off its hinges (photographs 22 and 23).

Reclamation staff partially shut the No. 2 ring follower gate (approximately 50-60 percent open) by gravity action by opening the control valves of the hydraulic operating system. Gravity closure of the ring follower gate caused the ruptured outlet pipe to act as an eductor which drained the valve structure in a very short period of time thereby stopping further flooding of the powerplant. Electrical power was later restored and the ring follower gate was completely closed stopping all water release from the ruptured outlet pipe.

The bulkhead gate was later installed to completely isolate outlet pipe No. 2 from the reservoir permitting inspection, testing of the ring follower gate, maintenance, and repair activities to begin. There was some confusion about installation of the bulkhead gate as plant personnel indicated that the Standing Operating Procedures were not very clear.

Action was also taken to inspect and determine the structural adequacy of outlet pipe No. 1. Interior access for inspection of the outlet pipe No. 1 was made more difficult due to the required releases of cold water for the gold medal fishing area located downstream of the outlet works. Due to the loss of all three turbine units, water releases were made through the spillway gates and outlet pipe No. 1. Closure of outlet pipe No. 1 for an interior examination would have resulted in great harm to the fish due to high water temperatures and less than adequate flow releases. However, a directive was issued to obtain assurance that the No. 1 outlet pipe was safe to operate. It was made clear that safety came first and the No. 1 outlet pipe would be shut down if exterior inspections were inconclusive.

Test methods were used to determine the adequacy of outlet pipe No. 1 via exterior inspection only. Ultrasonic thickness measurements were taken from the outside of the outlet pipe near the concrete to steel interface area. All thickness measurements were equal to or greater than ½-inch as shown on the original design drawings. Accelerometers were installed on outlet pipe No. 1 to monitor any significant changes in vibration levels. Noise level readings were taken every 2 hours using a decibel meter to monitor any changes. Based on the data obtained, it was determined that outlet pipe No. 1 was in good condition but an interior examination should be performed as soon as possible for verification. It was decided to postpone the inspection of outlet pipe No. 1 until at least two of the turbine units were operational to provide the required amounts and suitable temperatures of the water releases.

The interior of outlet pipe No. 1 was examined on July 1, 1997. There was no cavitation damage noted. There was a significant loss of the coal tar epoxy coating observed and some very minor surface rusting with no evidence of metal loss in the pipe shell (photographs 24 and 25). There was no movement observed of the expansion joint as the metal stop was centered between the inner sleeves of the expansion joint (photograph 26). Outlet pipe No. 1 was determined to be in good condition and safe to operate.

Flooding at Flaming Gorge started in the Ring Follower Gate (RFG) chamber and continued into the RFG control house and into the powerplant where electrical equipment was damaged on the main powerplant floor (elev. 5621.00) and floors below. There was an accumulation of approximately 1-2 inches of water on the first two floors of the powerplant and approximately 6 feet of water in the penstock gallery. Flooding also occurred in the parking lot to the south of the powerplant and a minor amount of water flooded onto the transformer deck between the powerplant and the dam. Levels of the powerplant and dam above the main floor did not receive flooding.

Miscellaneous minor damage occurred throughout the affected areas and included paint discoloration, damaged personal computer equipment, wet and damaged hand tools, and water damage to instruction manuals and catalogs used by the mechanics. Also, shop tools which were in the path of the water exiting the break room received minor damage, and spare parts and shop stock stored in bins were damaged.

4.0 CAUSAL FACTORS/INAPPROPRIATE ACTIONS

4.1 <u>Cavitation Damage Causes Rupture of Outlet Pipe No. 2</u> (PRIMARY EVENT)

a. Gate Hanger Not Used (Inappropriate Action)

Basis: The cavitation damage noted within the first 5 to 6 feet downstream of the ring follower gate is indicative of damage caused by misalignment of the ring follower gate sleeve with the ring follower gate body due to not using the manual screw-type gate hanger. Plant personnel indicated that the ring follower gate for outlet No. 2 also had a tendency to drift downward, sometimes as much as 3-4 inches while in the full open position due to oil leakage in the hydraulic operating system. Subsequent testing of the ring follower gate after the outlet pipe rupture showed that the gate drifts approximately 1 inch per day. The hoist cylinder packing for ring follower gate No. 2 has a substantial amount of leakage past the packing and was scheduled for overhaul in the fall of 1997. The former operator at Flaming Gorge reported that the hanger for gate No. 2 would never engage properly and therefore was never used. Engaging the hanger would have prevented the sleeve of the ring follower gate from drifting downward into the path of flow and would have likely prevented the cavitation erosion and subsequent failure. Ring follower gates are designed to operate only in the fully open or fully closed positions. Any movement from the fully open position will cause a severe disruption in the flow path and will cause cavitation and ultimately failure as occurred here.

ROOT CAUSE

The operators apparently did not understand the importance of the gate remaining in the fully open position. The design of the gate hanger may have been less than adequate but because the importance of the gate remaining open was not recognized, a redesign was not requested. The DOC and the SOP did not communicate the importance of the gate position nor was there any training provided on the operation of the gate. The SOP does not address the gate hanger or its use at all. The DOC mentions it but doesn't go into detail on how to use it or why it should be used. Management may have expected the operators to fully understand the equipment, but with no guidance or training this expectation was not met. The root cause of this inappropriate action was the lack of guidance and training.

RECOMMENDED CORRECTIVE ACTIONS

<u>**Install New Gate Hangers on Ring Follower Gates**</u>

It is recommended that new gate hangers be designed and installed to hold the ring follower gates in the full open position any time the outlet works are in operation, or modify the control system to monitor gate position and keep the gates open. The cavitation damage that led to the pipe failure was most likely caused by the ring follower gate drifting down into the path of flow. The current screw-type gate hanger is difficult to engage and would be impossible to disengage in an emergency situation when hydraulic power to the gate is lost. A shear pin-type hanger that allows the gate to close under emergency situations by breaking the hanger pin would be desirable. A backup hydraulic system would still be required to close the gate if the primary pumps are lost. Another method of keeping the gates open would be to modify the control system to automatically operate to keep the gates open. It is recommended that the new gate hangers and modification of the hydraulic operating system to include a restoring cycle for the ring follower gate be designed and installed prior to use of the outlet works pipe for river releases next spring.

Provide Training on Operation of Equipment

A review of plant equipment should be made and arrangements made to provide training on any pieces of equipment that operations is unclear on exactly how it operates.

Revise SOP to include use of Gate Hanger

It is recommended that the SOP be revised to include requiring engaging the gate hanger any time the outlets are used for more than just testing. As stated above, new gate hangers should be installed before next spring.

b. Inspection, Identification, and Repair of Damaged Area Less than Adequate (Inappropriate Action)

Basis: Pitting of the outlet pipes just downstream of the ring follower gates was noted in the 1993 Review of Operation and Maintenance Examination Report and a category 2 recommendation was made to "clean and repair corrosion damage in outlet pipes No .1 and 2." It is believed that this damage in pipe No. 2 was actually due to cavitation and was probably misidentified as corrosion damage, thus inferring that the damaged area only needed to be cleaned and repainted. The inspection team during this review did not include a qualified mechanical engineer familiar with cavitation damage. There is no record that a qualitative measurement was taken to determine the extent of metal loss that had occurred in the outlet pipe shell due to observed damage. Non-destructive examination techniques such as ultrasonic methods should have been used to determine actual pipe wall thickness.

This recommendation was addressed and completed in 1994. The typical method for repairing corrosion damage is to clean the rusted surface by wire brush and then coat the damaged area with coal tar epoxy. The subsequent 1996 RO&M examination report stated that there was no evidence of cavitation damage and the coating was in good condition. It should be noted that the coal tar epoxy coating is very thick and would have masked any damage and metal loss that may have occurred prior to repainting of the damaged area.

ROOT CAUSE
The root cause of this action was not having a directive or policy on the qualification of inspectors on review teams. Currently and at the time of the 1993 RO&M review there was no policy or directives on qualifications of water or power review inspectors. The main purpose of these inspections is to ensure that Reclamation facilities are being maintained adequately. In order for these inspections to meet this purpose the inspectors must understand and have experience with the type of equipment or structure being inspected.

RECOMMENDED CORRECTIVE ACTIONS
Include Qualifications of Inspectors in Directives or Policy on O&M Reviews

When directives for RO&M, SOD/SEED, and Power reviews are written, include qualifications requirements for inspectors.

c. **Cause of Noise Not Investigated Adequately (Inappropriate Action)**
Basis: Several Flaming Gorge personnel commented that the noise level from the outlet works operation increased several days prior to the incident. Some commented that they noticed this as early as Monday, June 16. The operators log shows no mention of the noise level. At midday on Friday, June 20 the engineering technician took noise level readings at the bottom of the RFG chamber with a Simpson model 884 decibel meter. The reading was 113 dB. He did not report this reading to anyone prior to the incident nor is it in the operators log. There are no historical noise level readings to compare this measurement to. There was no investigation of the cause of the loud noise coming from the outlet works.

The Operations and Maintenance Superintendent, who had 26 years of operations experience at Flaming Gorge, retired in early 1997. The Control Room Operator who worked with the superintendent for approximately 7 years moved to an operations position at Glen Canyon on June 9, 1997 . (It was fortuitous that this operator was in the vicinity of Flaming Gorge and could be reached to assist in the emergency.) The current Control Room Operator has been stationed at Flaming Gorge since approximately May 27, 1997, but has extensive operations background.

The current Power Facility Supervisor has held this position since May 11, 1997, but has been employed at Flaming Gorge since 1985. The current Plant Maintenance Supervisor has held this position for approximately 18 months. In addition, the on-site engineer position has been vacant for several months.

River outlet operation at the prevailing hydraulic head is rare. The last time such operation occurred was 1986; therefore, the current staff would have little or no knowledge (or memory) of normal noise levels under these operating conditions. This factor led the plant personnel to believe that the high noise levels were normal.

Had the staff had more operating experience with normal operation (and noise levels) of the outlet works, it might have been apparent that the noise levels heard were unusual and indicative of a problem. The increased noise level may have been investigated and possibly resolved.

The limited individual and aggregate amount of time and experience operating and maintaining the outlet pipe hampered their ability to detect, identify, and understand the significance of the increased noise levels. There are no procedures in place for investigating unusual noises or vibrations nor was there any training available to recognize a problem such as this.

The guidelines on reporting and investigating unusual noises or vibrations are less than adequate. There are no known records of noise (decibel) level or vibration measurement readings during normal operation at the prevailing hydraulic head. Therefore, there are no baseline readings by which to have compared noise levels or vibration data in this incident. In addition, there is no procedure identified to determine the noise level or vibration levels during operation of the outlet pipes. Had there been baseline readings available and a procedure in place, an increase in noise or vibration levels may have led plant personnel to perform further investigations into the possible cause of these increased noise or vibration levels.

Procedures or guidelines should be developed and training provided to communicate management's expectations.

ROOT CAUSE
The root cause of this action was the lack of guidance, procedures, and training on investigating unusual conditions.

RECOMMENDED CORRECTIVE ACTIONS
Instrument the Outlet Tubes to Measure or Monitor Vibration

The relative increase in noise level noted by several plant personnel during the week prior to the failure of the pipe would indicate that vibration levels of the outlet pipe increased as well prior to failure. Noise level, as heard by the human ear, is a very subjective measurement. A quantitative measurement with a decibel meter would be more effective, but in a powerplant there are a number of noise sources that may be contributing to overall noise levels. In this case, the major concern is the condition of the pipe itself. To effectively monitor the vibration of the pipe, accelerometers mounted directly to the pipe would provide a quantitative measurement of the pipe vibration. Baseline readings would have to be taken to determine "normal" limits for different discharges and reservoir elevations. The output of the accelerometers could be set up to continually monitor the vibration levels and provide an alarm if the levels increased above a predetermined point or periodic readings could be taken while the outlets are in operation. It is recommended that vibration measuring equipment for the outlet pipes be procured and used whenever the outlets are in operation.

<u>Clarify Management's Expectations Regarding Investigation of Unusual Conditions</u>

Management's expectations regarding the investigation of unusual conditions or perceived unusual conditions needs to be clarified. Management needs to emphasize and encourage plant personnel to vocalize and take action when there is any indication that any piece of equipment is not operating properly or that something has changed. Training should be provided to communicate management's expectations to plant personnel.

RELATED RECOMMENDED CORRECTIVE ACTION
<u>Thoroughly Inspect and Perform Maintenance on the Outlet Works Regularly</u>

It is recommended that maintenance on the outlet works include a thorough inspection of the outlet pipes annually and immediately after any releases, paying close attention to the area directly downstream of the ring follower gates looking for any evidence of cavitation damage. Also, the expansion joints should be checked for tightness and leakage annually, prior to operation, and regularly during any operation of the outlet works. When outlet works are in operation, they should be checked daily, including weekends and holidays, for any unusual conditions such as leakage, excessive noise, or vibration.

4.2 <u>Flooding</u> (Secondary Event)

Contributing Causal Factor to Flooding

Inability to Immediately Close the Ring Follower Gate (Contributing Causal Factor)

Causal Factors to Inability to Close Gate

a. Lack of Alternate Power Source
Basis: There is no alternate source of power (electrical or hydraulic) for emergency operation of the ring follower or hollow jet valves. Without power from power board MSB available, there was no way to completely close the ring follower gate to stop flooding. Had there been an alternate source of power located in an area free of flooding damage, complete gate closure would have been accomplished sooner, thus mitigating the flooding damage that occurred in the powerplant.

ROOT CAUSE
The review of an emergency power supply for the outlet works during the original design was less than adequate. A backup electrical power supply would not have allowed the gates to close any sooner as there wasn't any means to feed the power to the pump

motors. It should be noted that plant personnel had recognized that this was a problem and a propane-powered pump was on order at the time of the incident.

RECOMMENDED CORRECTIVE ACTION
Install a Backup Emergency Hydraulic Pump or Accumulator Tank

It is recommended that a propane or gasoline-powered hydraulic pump for the ring follower gates be installed to allow the gates to be operated when the electrical power is not available. As noted above, this pump had already been ordered. As with the controls themselves, the pump and engine must be installed in a location that is protected and accessible. Another alternative would be to install a hydraulic accumulator tank that could provide pressure to close the gates in the event primary power is lost.

b. Ring Follower Gate Controls in Vulnerable Location
Basis: The controls for the ring follower gate are in the control house which flooded very soon after the pipe ruptured. This design does not accommodate emergency operation of the gates under flooding conditions. With high water level in the control house and water pouring down the access steps, it was very difficult and dangerous for the staff to access and operate the controls. Had the controls been located in an area not subject to flooding, the ring follower gate could have been closed more quickly.

ROOT CAUSE
The original design of the outlet works is less than adequate in that a failure, such as a pipe rupture in this particular area, was not provided for.

RECOMMENDED CORRECTIVE ACTION
Move RFG Hydraulic Controls to a Less Vulnerable Location

The current location of the ring follower gate controls, inside the gate house, made accessibility during flooding very difficult. Had the failure been larger or simply on top of the pipe rather than on the bottom, access may have been impossible. The current location also leaves the electrical controls vulnerable to flooding. It is recommended that the controls be moved out of the gate house to a location that would be protected and accessible even in the event of a major leak or failure in the gate house. Optional locations would include next to the gate house or on the gate house roof.

c. O&M Staff Not On-Site to Close Gate
Basis: Prior to the mid-1970s, Flaming Gorge was staffed around the clock with operators. Since then (when plant automation was installed) operations is staffed 8 hours per day, Monday through Friday. This incident occurred on Saturday when no operations personnel, or other Reclamation staff, were on site. Flooding continued until staff arrived and closed the gate. The delay caused more extensive damage in the powerplant. Had O&M staff been on site, the gate may have been closed more quickly, thus mitigating

flood damage inside the powerplant. This action would have still required someone to enter the flooded gate house to operate the ring follower gate.

ROOT CAUSE
There was less than adequate expectations by the management for personnel availability.

RECOMMENDED CORRECTIVE ACTION
Have Key Personnel Carry Pagers

Key personnel (e.g., operator, maintenance chief, and the facility manager) should carry pagers at all times so they can be reached in the event of an emergency. Consideration should be given to provide Glen Canyon operations center with outlet works gate and valve position indication, video images of remote powerplants, and remote control operation of the outlet works gates and valves.

d. Remote Control Not Available
Basis: Remote control (either at Flaming Gorge or at the Glen Canyon control center) is not available in the current installation. Had this control been available, more rapid gate closure would have been possible provided the controls were not damaged by flooding and electricity to the controls was available.

ROOT CAUSE
There is a less than adequate design of the ring follower gate controls for an unmanned plant.

RECOMMENDED CORRECTIVE ACTION
Automation of Gates and Valve Controls

Currently the controls for the outlet works (ring follower gates and hollow jet valves) are completely manual. To provide river flow in the event that all three units are lost, one hollow jet valve is left open approximately 20 percent and the manual valves for the ring follower gate controls are positioned to allow the corresponding ring follower gate to open by simply starting the pump. This requires the ring follower gate to open under unbalanced head, an operation the gate was designed to be capable of performing, but it was not the intent of the original design. Other than this operation, the current controls don't allow for operating the gates automatically or remotely. Following the pipe failure, provided that power to the controls was not lost, automatic closure of the ring follower gate could have prevented much of the damage that occurred in the plant due to flooding. As a minimum, it is recommended that the ring follower gate control be automatic. This will involve installing solenoid or motor-operated shutoff and control valves. To eliminate the need to open the ring follower gate under unbalanced head, the filling line valves, drain valve, and the hollow jet valves should be automated as well. Once all the control valves can be electrically operated, a programmable logic controller could be used to sequence their operation to automatically operate the gates and valves. A redundant controller should be part of the system to provide control in the event of failure of the primary control when the plant is unmanned. The ring follower gate controls should also be provided with an automatic position restoring system to prevent the gate from drifting as a backup to an automatic/semi-automatic gate hanger.

The outlet works are limited to 2000 cfs each to limit the velocity of the water flow through the pipes. As the reservoir elevation increases, the maximum allowable opening of the hollow jet valve decreases. At the time of the failure the allowable opening was 72 percent. Opening the hollow jet valves above the maximum allowable opening can shift the flow control from the hollow jet valve to the pipe, resulting in very high vibration levels. Hollow jet valves, because of their design, will tend to drift open if there is any leakage in their hydraulic operating systems. When the valves are operated close to their maximum allowable opening, any drifting could lead to a serious vibration problem. A closed loop feedback control system to maintain hollow jet valve position should be considered. This would require electrically operated valves and a programmable controller and could be part of automating the controls.

e. **No Automatic Shutdown of Gates**

Basis: There is presently no automatic shutdown of the ring follower gates on high water level in the gate chamber. There is neither the high water sensing capability nor control system hardware in place to accomplish this. On the other hand, the plant is protected for similar flooding from ruptured penstocks by automatic penstock gate closure, and the ring follower gates are capable of closing under unbalanced head. Therefore, the design is considered to be less than adequate. Had there been the capability to automatically shut down the ring follower gates, flooding would have stopped very soon after pipe rupture, provided that there was power to operate the pumps available or an auxiliary source of pressure such as an accumulator tank.

ROOT CAUSE

The plant automation design is less than adequate with respect to the ring follower gate controls.

RECOMMENDED CORRECTIVE ACTION

<u>Automation of Gates and Valve Controls</u>

See 4.2d above.

f. **No High Water Alarm**

Basis: There is no high water alarm for the ring follower gate chamber. This is less than adequate design, particularly in view of the frequent unattended operation of the plant. Had there been a high water alarm more immediate corrective action could have taken place.

ROOT CAUSE
There is a less than adequate design of the ring follower gate controls for an unmanned plant.

RECOMMENDED CORRECTIVE ACTION
Install High Water Alarm in RFG Chamber to Shut Down RFGs

It is recommended that a high water alarm be installed in the ring follower gate chamber, set up to alarm the control center in Page, and also automatically shut the ring follower gates. This would be similar to high water alarms in turbine pits in most powerplants that automatically close the penstock gates.

4.3 Powerplant Floods (SECONDARY EVENT)

Causal Factors

a. Pipe Chase Not Sealed
Basis: There is an open pipe chase between the ring follower gate control house and the "mechanics break room" (Tool Room - Rm. 311) in the powerplant and there is no watertight sealant in the chase to prevent water from passing through it. In current Reclamation designs, watertight (RTV, etc.) sealants are specified to be installed to prevent such flooding. However, there appears to be no requirement that existing facilities retrofit this type of protection. Had there been such a requirement, sealant would have been installed, thus preventing water from entering the powerplant from the pipe chase.

b. Passage Door Not Watertight
Basis: The passage door between the ring follower control house and the powerplant is not watertight. Water flowed underneath the door and through the ventilating panels in the door. Had the door been watertight, water would not have entered the powerplant in this manner.

ROOT CAUSE (4.3a and 4.3b)
Design less than adequate. Original design did not consider ring follower gate house flooding.

RECOMMENDED CORRECTIVE ACTION (4.3a and 4.3b)
Seal Leakage Paths from Ring Follower Gate Control House to Powerplant

It is recommended that the pipe chase from the gate house to the break room be closed with some type of approved fire/water stop material. The door between the gate house and the machine shop should be abandoned and sealed if there is no conflict with the Life Safety Code.

c. **Drains Blocked or Clogged**

In some cases, drains in the plant were less than effective because they had been blocked or became quickly blocked with loose paper in the plant carried by the water.

ROOT CAUSE

Loose paper stored where it could get into drain.

RECOMMENDED CORRECTIVE ACTION

Check Powerplant Drains Periodically

Install oversized screens above drains to capture loose debris but still have enough flow area to adequately drain excess flows.

4.4 Water Floods Exciter Cubicle (SECONDARY EVENT)

Causal Factors

a. **Floor Penetrations Not Sealed**

Basis: Floor penetrations (e.g., embedded conduits beneath the governor cabinets) in the main are not sealed watertight, thus permitting water to flood to the equipment on the floor below. Provisions for sealing floor penetrations in new facilities are made in new specifications for flooding and fire protection services. Had there been a Reclamation requirement to apply sealant to floor penetrations in existing facilities, sealant would have been installed, thus preventing water from flooding the exciter cubicle.

ROOT CAUSE

Design less than adequate. Original design did not consider consequences of flooding upper floors.

RECOMMENDED CORRECTIVE ACTION

Seal floor penetrations

Seal floor penetrations and conduits with approved fire/water stop material.

b. **Cubicles In Vulnerable Location**

Basis: The exciter cubicles are located on the 5607.25 elevation, one floor below the main floor where the generators and governors are located. The exciters are located on the same elevation as the turbine pits and miscellaneous water piping, thus making them susceptible to water damage. Water flooding from the powerplant main floor easily entered the excitation cubicles and damaged the sensitive electronic equipment inside. Had the exciters been located on the main floor as in most designs, water would not have flooded the cubicles.

ROOT CAUSE
Design placing exciters on lower level less than adequate.

RECOMMENDED CORRECTIVE ACTION
Protection of Exciter Cubicles

Consider relocation of the exciter cubicles to a higher elevation or consider providing additional flooding protection to the cubicles.

4.5 Generator Cooling Water Pump Motor Starters Flooded (SECONDARY EVENT)

Causal Factors

a. Conduits Permit Water
Basis: Embedded power conduits underneath the unit power boards terminate flush with floor elevation 5621.00 and they permit water to enter and drain down to electrical equipment such as generator cooling water pump motor starter cabinets. Provisions for sealing electrical conduits in new facilities are made in new specifications for flooding and fire protection purposes. Had there been a Reclamation requirement to apply sealant to conduits in existing facilities, sealant would have been installed, thus preventing water from flooding the motor starters.

ROOT CAUSE
Design less than adequate.

RECOMMENDED CORRECTIVE ACTION
Seal Power Conduits

Seal embedded power conduits where appropriate.

4.6 Power Board MSB Floods (SECONDARY EVENT)

Causal Factors

a. Board Directly In Path Of Water
Basis: Power distribution board MSB that supplies power to the ring follower gate and hollow jet valve controls is mounted on the east wall of the powerplant directly below the passage door connecting the ring follower gate control house to the powerplant. (See 3.3b). Water naturally flowed down the wall into the power board, shorting out components. Had board MSB been installed in a location other than in the path of the water, failure would not have occurred. (Sealing off the Ring Follower Gate control house from the powerplant will eliminate this problem.)

ROOT CAUSE
Design placing distribution board in potential path of water less than adequate.

RECOMMENDED CORRECTIVE ACTION
Modify the existing ring follower gate and hollow jet valve power supply

Consider relocating the existing distribution board MSB to be out of the path of water entering the plant. (Not required if passage door into plant from the control house is adequately sealed.)

4.7 Documentation Less Than Adequate (Inappropriate Action)

a. A record of protective relay targets was not made by the operator subsequent to the event.
Basis: Standard procedure for follow up to any unusual occurrence is to log the protective relay targets for analysis. A form is provided for this and a stock is located on a holder on the control board. An informal inspection of the relays later by others showed that the Unit 2 Loss of Field relay and all three generator lockout relays had operated. The record of protective relay targets, created as soon as possible after the incident, is very important in analyzing an incident such as this. As soon as O&M personnel begin restoring the plant to normal operation, relays are reset and the information is lost if not documented.

ROOT CAUSE
Guidance for documentation of events less than adequate.

RECOMMENDED CORRECTIVE ACTION
Emphasize Management Expectations Regarding Event Documentation

Improve management expectations and communications regarding event documentation. Provide training on required procedures.

b. Emergency Action Plan Documentation not Complete.
Basis: The Emergency Action Plan (EAP) procedure in the SOP requires that a Telephone Report of Water and Power Interruptions and Facility Failure (Form 7-1792) "be maintained at all steps of the communication network". This form had not been completed at the facility at time of this review. Properly maintained, this form provides valuable, easy-to-find information regarding the incident which becomes part of the operators log and which is useful in analyzing the event. It should also be noted that use of the Emergency Notification System as contained in the Standing Operating Procedures was not utilized during this emergency.

ROOT CAUSE
Failure to follow SOP.

RECOMMENDED CORRECTIVE ACTIONS
<u>Provide Training on EAP Procedures</u>

Provide training to plant personnel on EAP contained in the SOP and on management's expectations concerning following SOP and EAP.

4.8 Public Safety Issues

The investigative team is seriously concerned about the safety of the public in this kind of incident. Serious injury or loss of life was avoided by providence only.

The last Reclamation employee to leave the facility on Saturday June 21 was the janitor. He left at approximately 15:40 and reported that he had seen no flooding in the powerplant or in the parking lot adjacent to the outlet works where he parks his car. The last guided tour of the facility began at 14:30 and concluded at 17:20; there were 36 people including one handicapped person on this tour. The tour guides reported seeing no flooding in the powerplant at the end of the tour. Prior to 18:06 the powerplant main floor (and thus some parts of the tour route) had flooded. Approximate time from the end of the last tour to flooding of the plant main floor: 50 minutes.

The tour route includes a visit down the west stairwell to the 5608.50 and 5607.25 elevations where visitors can view the Unit No. 1 turbine / generator shafts rotating. This is one of the paths that the water took to lower elevations when the powerplant main floor flooded. Water quantity and pressure were sufficient to break the sheetrock on the 5608.50 elevation to continue down the next stairwell. Water may have been 3 feet high in this corridor. THERE IS ONLY ONE PATH OF EGRESS FROM THIS AREA FOR TOUR GUIDES AND VISITORS - VIA THE STAIRWELL. All doors from the area were locked per standard procedure for security reasons.

Had tour participants been in the turbine shaft viewing area or on the landing just above when the plant main floor flooded they would have been trapped by water coming down the stairwell. Injury and / or death could easily have resulted from the force of the water and panic response.

RECOMMENDED CORRECTIVE ACTION
<u>Limit Extent of Tours</u>

It is strongly recommended that visitor tours of the elevations of the plant below the plant main floor be eliminated to prevent possible hazard of trapping visitors during an emergency.

5.0 GENERIC IMPLICATIONS FOR RECLAMATION

This section provides a list of the generic implications of the causal factors. The content of this section will focus on the areas that may apply Reclamation wide to prevent similar event occurrence.

1. Current inspection procedures for steel outlet pipes are less than adequate. Presently, steel outlet pipes are typically examined visually subject to availability, and no other qualitative testing is performed. The outlet pipes should be examined similar to the way penstocks are addressed by the Power O&M Program's Penstock Inspection and Safety Assessment Program. This program typically includes a thorough visual inspection, a detailed assessment using ultrasonic techniques to determine actual pipe shell thickness, testing of the emergency gates/valves, and a stress analysis based on actual wall thickness if the pipe shell has suffered any metal loss. It should be noted that all three penstocks at Flaming Gorge were inspected and evaluated in February and March of 1997.

2. Policy or directives need to be developed on qualifications of inspectors on all O&M reviews. In particular, qualifications of inspectors for the mechanical equipment of spillways and outlet works at Reclamation facilities may be less than adequate. There is a lack of mechanical expertise in addressing the O&M issues of mechanical equipment at the facilities addressed by the combined facility reviews. The Combined Facility Review team members are typically individuals with civil engineering backgrounds with little or no experience with mechanical equipment. Mechanical engineers were participants of the O&M Reviews in the past, but this participation was eliminated in an attempt to reduce the costs associated with the reviews. Also, inspection and testing of this equipment during the reviews is often subject to availability due to downstream flow/irrigation requirements. Consideration should be given to performing mechanical reviews by qualified mechanical engineers similar to those done in the Power O&M Review Program. These reviews, testing, and inspection of the mechanical equipment could be performed prior to the Combined Facility Reviews when the equipment is available (i.e., inspecting the interior of the outlet pipes and performing functional gate tests). These mechanical reviews could combine a number of facilities within one week's travel period and thus make them more economically feasible as well as verifying the functionality and condition of the equipment. The results of these mechanical reviews could then be documented and included as part of the Comprehensive Facility Reviews.

3. The rupture of the Flaming Gorge outlet pipe should bring to the forefront the importance of the emergency gate/valve testing program. The ring follower gates at Flaming Gorge were successfully tested under unbalanced head condition in 1993. These tests determined that the ring follower gates had the capability to close under full flow, unbalanced head in the event of an emergency. It is extremely important that the emergency gates/valves at Reclamation facilities are tested and determined to be functional to instill the confidence

that an emergency such as the event that occurred at Flaming Gorge can be mitigated. There are still a number of Reclamation facilities that have not performed emergency gate/valve tests in over 30 years. We recommend that these facilities be directed to comply with testing program requirements as soon as possible.

4. The location of emergency gate controls and the backup emergency power supply at Reclamation facilities should be reevaluated to ensure that in the event of a pipe failure and subsequent flooding, the controls and backup power supply can still be readily accessible for operation. Automation of the outlet pipe emergency gates for emergency closure should also be considered, especially with many of Reclamation's facilities now being unmanned for long periods of time. Penstock emergency gates are typically automated to close in the event of a high water alarm or loss of penstock pressure. This type of alarm and relaying could also be used to automate the outlet works gates. The event at Flaming Gorge should also stress the importance of having a reliable backup power supply to operate the emergency gates in the event of loss of power.

5. Replacement of all non-shear pin screw-type gate hangers with automatic/semi-automatic gate hangers should be considered at all Reclamation facilities. The screw-type gate hangers are very cumbersome to engage and without the ability to shear in an emergency, will not allow automatic closure of the gate.

6. More detailed inspection of flexible joints such as expansion joints and bolted sleeve-type couplings should be performed each time the outlet pipe is put in service. These joints should be visibly and hand checked for loose bolts and leakage past the packing. This task should be included as part of the Standing Operating Procedures for outlet pipe and penstock operations at all Reclamation facilities and should also be included as a regularly scheduled programmed maintenance item.

7. Consideration should be given to installing high water alarms in valve pits with expansion joints and sleeve-type couplings. There have been several instances in Reclamation where leakage from these flexible joints has caused some flooding damage. Installation of the high water alarms would provide early notification and prevent or mitigate the damage due to flooding.

8. Consideration should be given to taking baseline noise level readings with a decibel meter and/or baseline vibration measurements of the outlet pipes when operating at full capacity. Many of Reclamation's facilities have undergone downsizing and have lost a great deal of experienced employees. Operation of the outlet works may be a seldom occurrence as in the case of the Flaming Gorge outlet pipe. The baseline noise/vibration readings would assist those inexperienced with outlet works operations to determine if the noise/vibration levels are within acceptable normal operating parameters. If the vibration/noise levels are substantially higher than those recorded during the baseline readings, it may be indicative of a problem occurring, thus triggering further investigation.

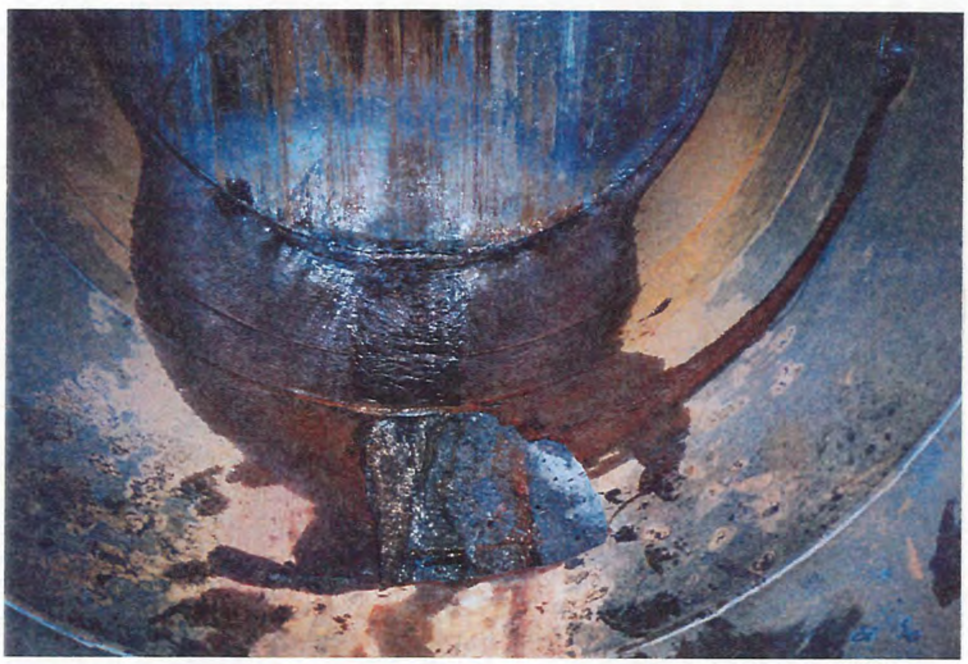
9. Understanding the operation of plant equipment is essential in keeping it maintained properly. As much of the equipment found in Reclamation powerplants and dams is unique to a particular facility, an operator or maintenance person that transfers to a facility may be familiar with similar equipment but not with the particularities of the equipment at the new facility. Training on how the equipment works and proper operational procedures should be provided to all personnel that may be called on to operate or maintain a piece of equipment.

10. A review of the operating instructions for ring follower gates and gate hangers at all Reclamation facilities should be performed to verify the procedures are correct.

11. Management at Reclamation facilities should have certain expectations for the operation and maintenance of their facilities. In order for these expectations to be met, they have to be communicated to their employees. One method of communicating some of these expectations is through the SOP. The SOP should contain correct operating procedures for the facility. Procedures in the SOP are only effective if they are used. Management needs to make sure that the SOP's are correct and that their personnel are following the SOP's. Management should expect their facility to have an appropriate level of maintenance. To convey these expectations to employees requires adopting written guidelines such as FIST bulletins, providing training to employees, and showing support for maintenance activities.

6.0 PHOTOGRAPHS

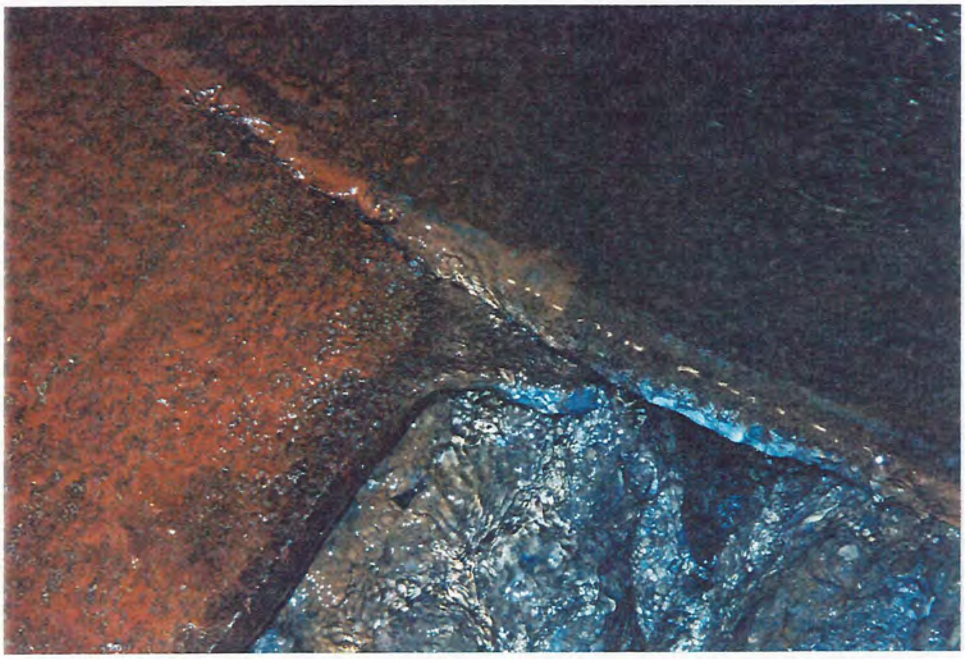
Photograph 1 - Exterior view of damage to outlet pipe No. 2.



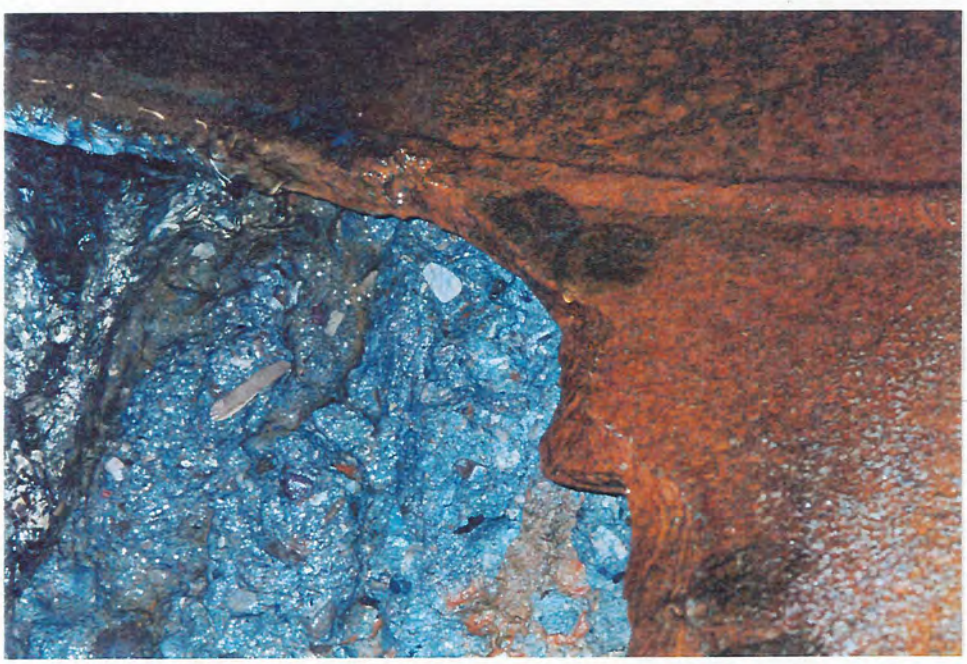
Photograph 2 - Interior view of damage to outlet pipe No. 2.

Photograph 3 - Interior view of damaged area of outlet pie No. 2.

Photograph 4 - Concrete-steel outlet pipe interface. Note spalled concrete around circumference of outlet pipe which is indicative of damage caused by vibration.

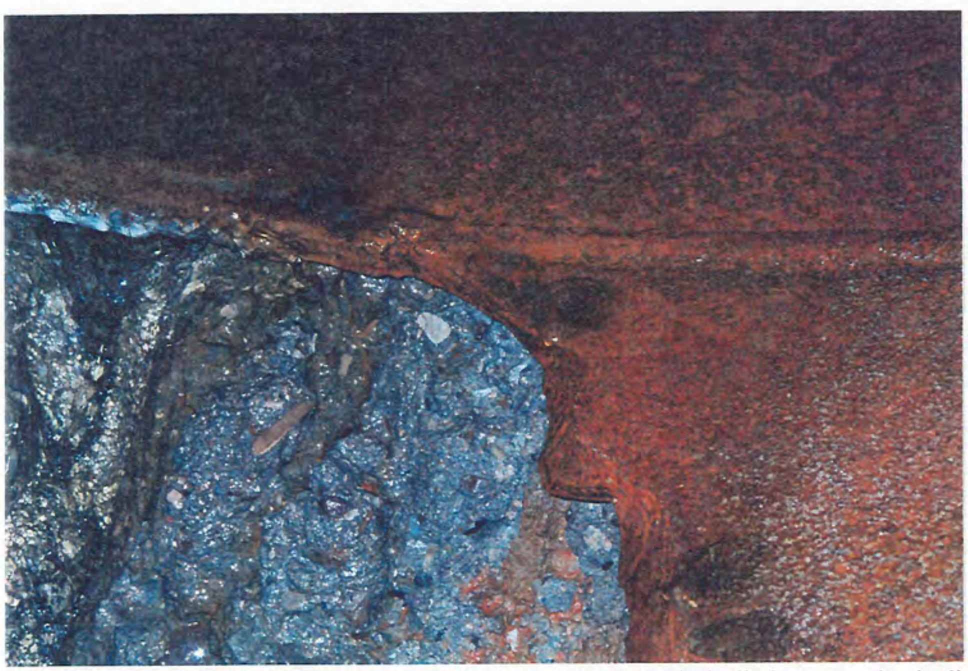


Photograph 5 - Left side of fractured weld looking upstream. Note cavitation pits.

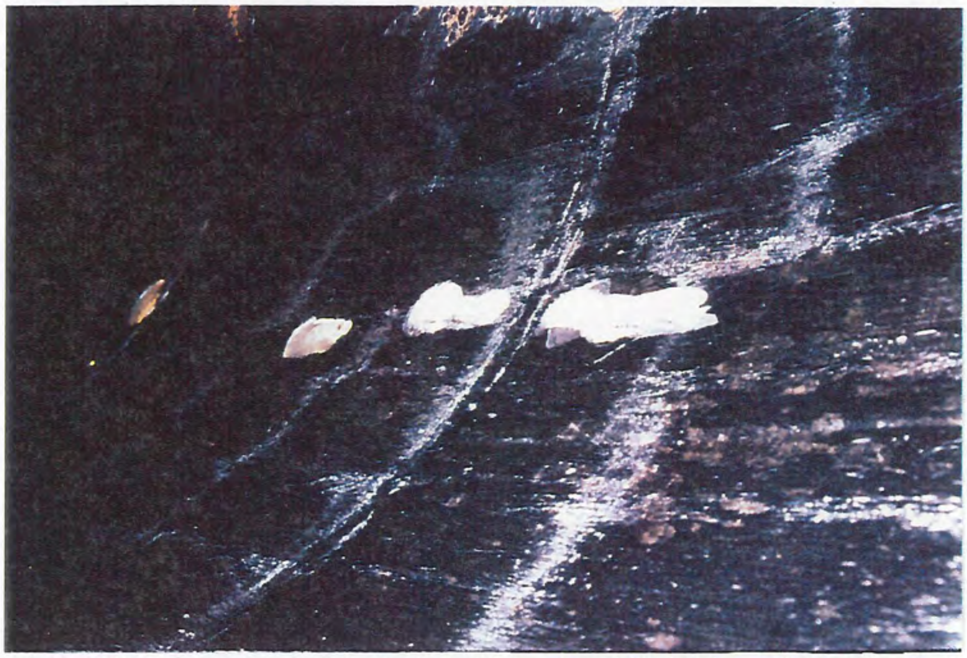


Photograph 6 - Right side of fractured weld looking upstream. Note large cavitation pit.

Photograph 7 - Fractured weld. Note crack extends between two large cavitation pits.



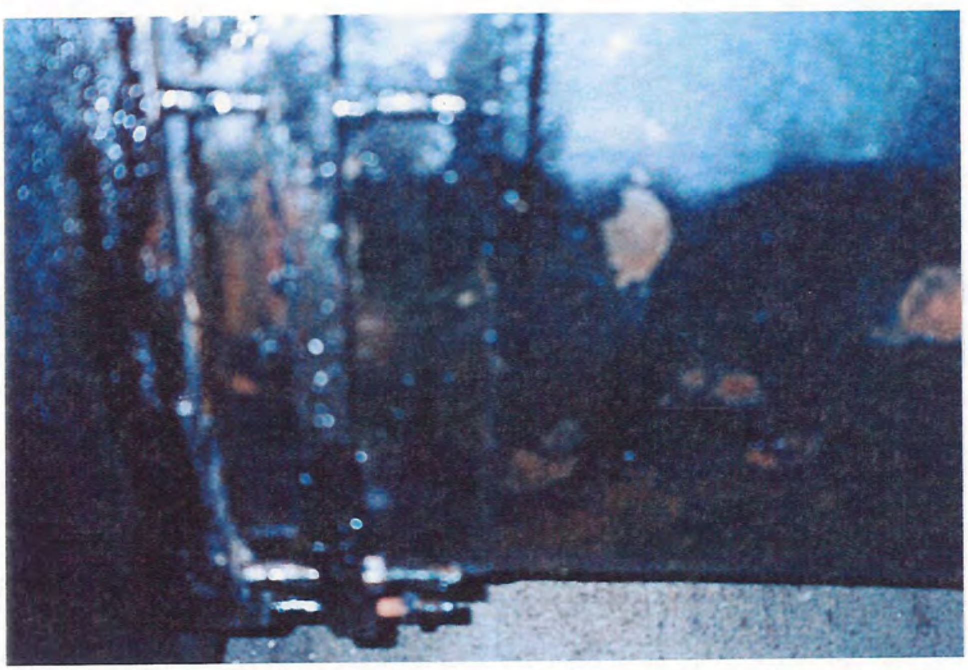
Photograph 8 - Upstream end of fractured weld. Note fractured shell that may be indicative of a crack that existed for a period of time.



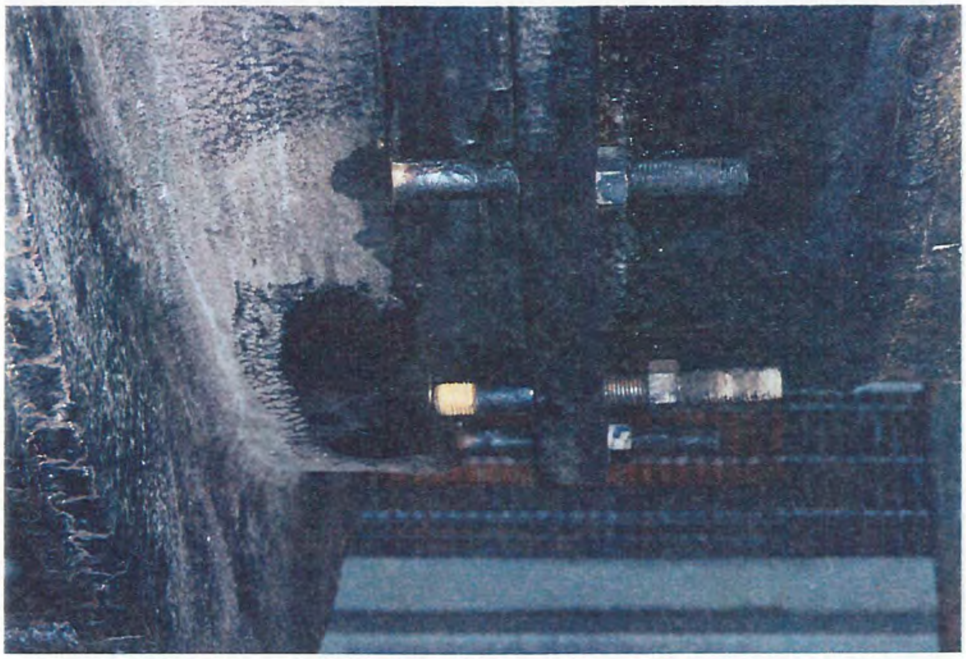
Photograph 9 - Damage to coal tar epoxy coating caused by broken piece of outlet pipe as it traveled through the outlet pipe.

Photograph 10 - Scrape marks where broken piece of outlet pipe traveled through stay vanes of the hollow jet valve.

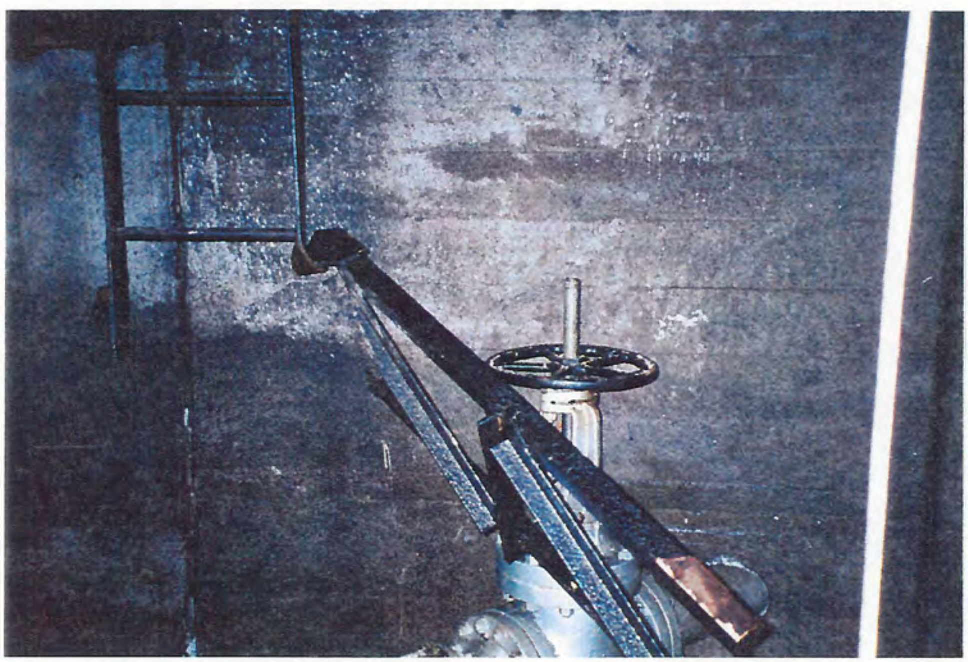
Photograph 11 - Hoist cylinders for ring follower gates located in gate control house.



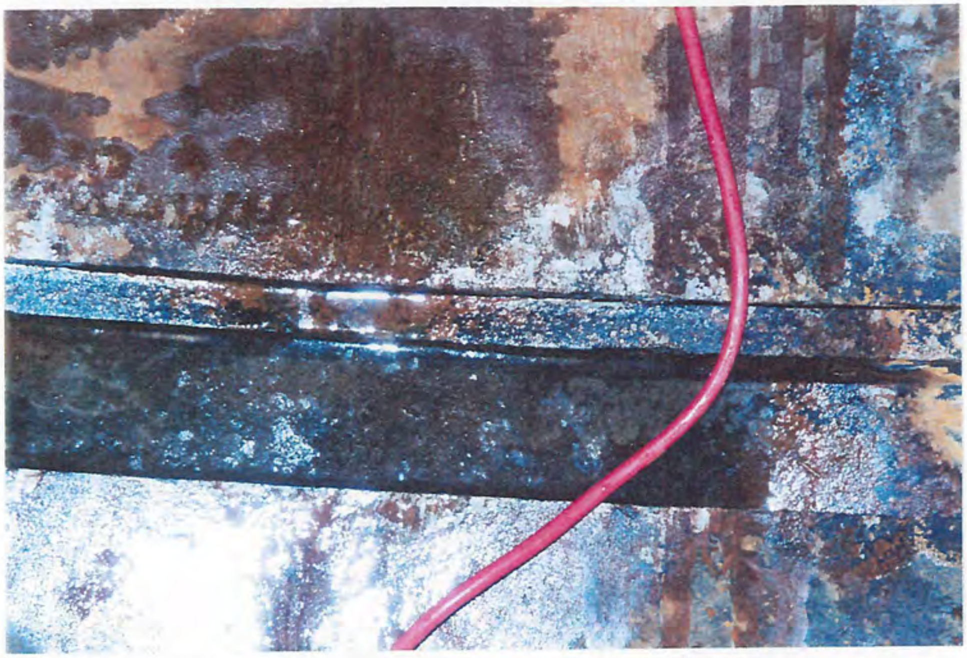
Photograph 12 - Exterior view of expansion joint on outlet pipe No. 2. Note missing bolts.



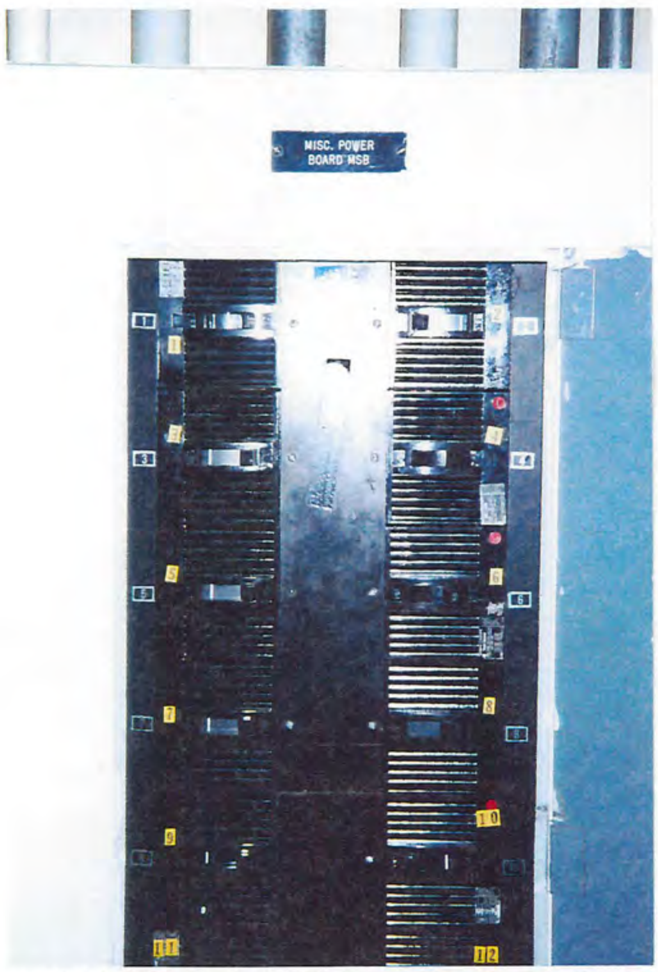
Photograph 13 - Exterior view of expansion joint on outlet pipe No. 2. Note how the nuts are backed off of the bolts.



Photograph 14 - Damage caused by leakage through broken outlet pipe to access ladder which was attached to the expansion joint.



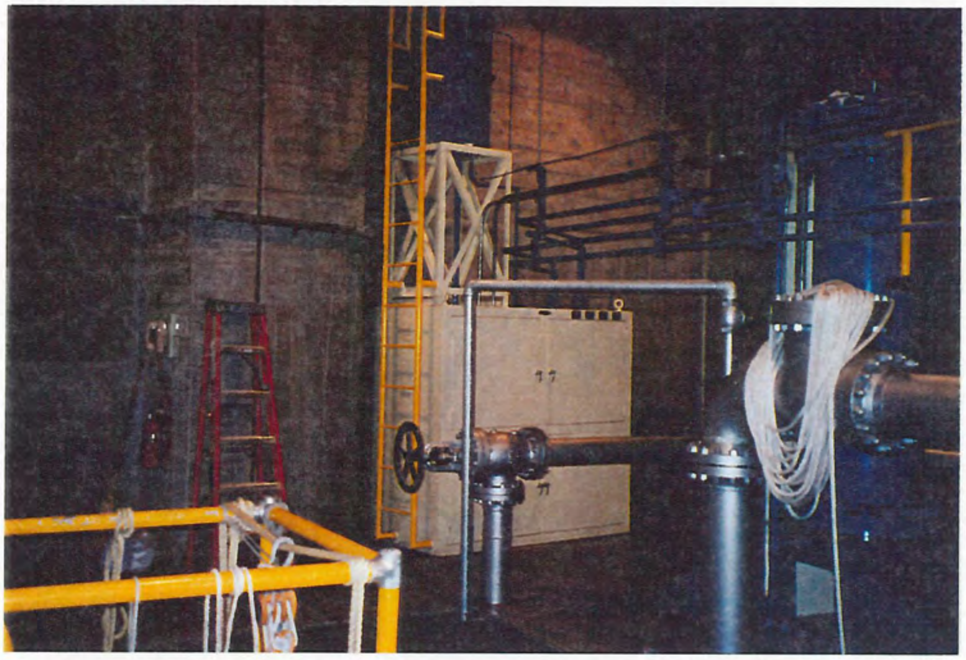
Photograph 15 - Interior view of expansion joint on outlet pipe No. 2. Note how metal stop is directly against the downstream inner sleeve.



Photograph 16 - 480 vac distribution board which supplies electrical power to both the ring follower gate control and the hollow jet valves. Flood damage made them electrically inoperable.

Photograph 17 - Exterior view of damage to roll-up door located in the ring follower gate control house.

Photograph 18 - Interior view of damage to roll-up door located inside the ring follower gate control house.



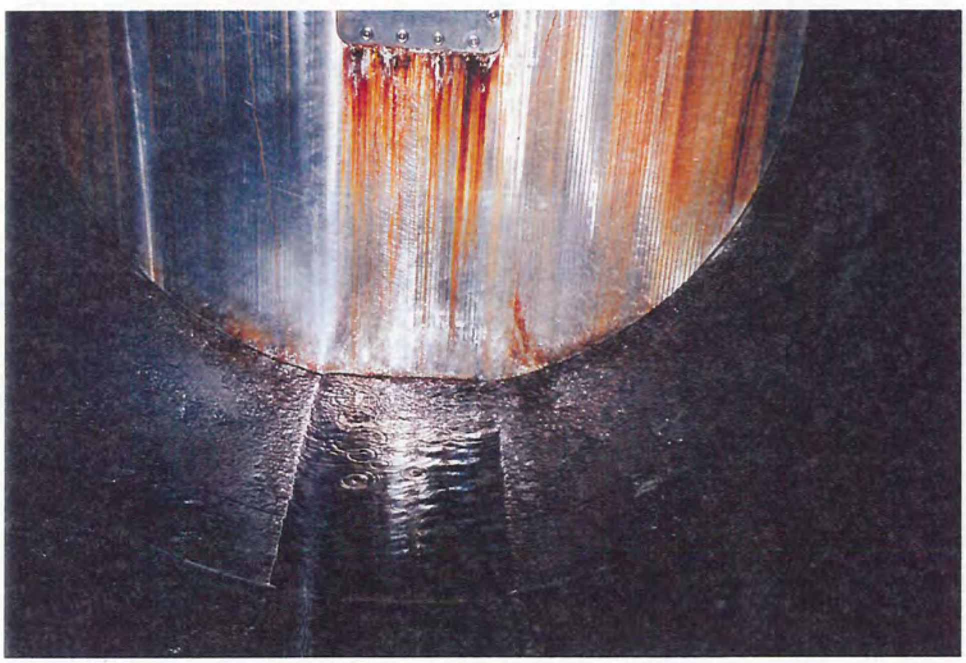
Photograph 19 - Control cabinet for ring follower gates located inside the control house.

Photograph 20 - Pipe chase located between the powerplant and the control house through which water entered the powerplant.

Photograph 21 - Access door between the powerplant and the ring follower gate control house through which water entered the powerplant.

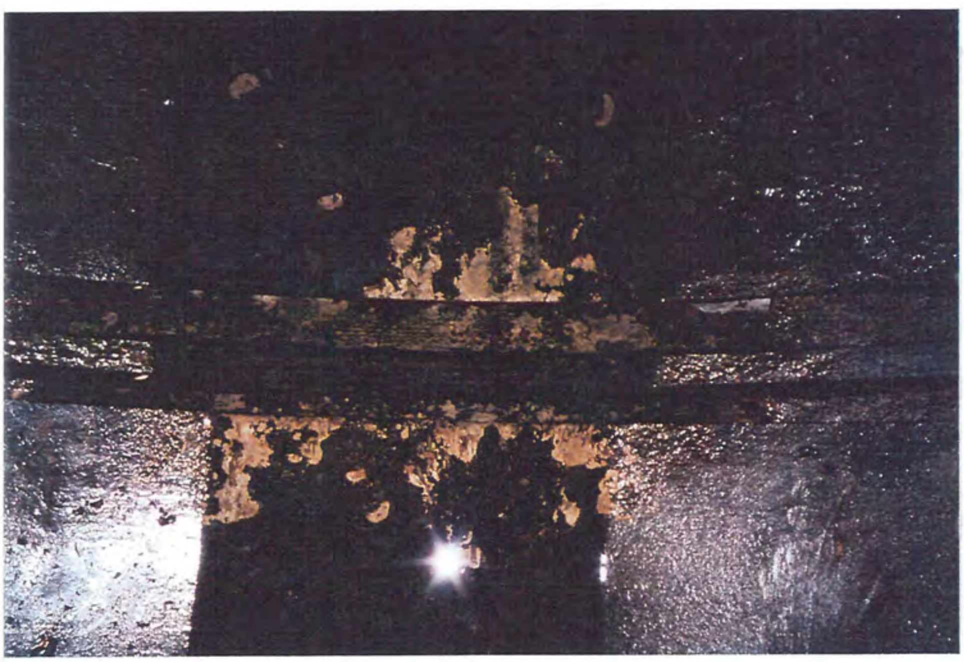
Photograph 22 - Location of break room access door which was damaged due to flooding.

Photograph 23 - Damage to break room access door caused by flooding.



Photograph 24 - Interior view of outlet pipe No. 1.

Photograph 25 - Invert of outlet pipe No. 1. Note missing coal tar epoxy but no evidence of metal loss due to cavitation.



Photograph 26 - Interior view of expansion joint on outlet pipe No. 1. Note how metal stop is located between the upstream and downstream inner sleeves of the expansion joint.

Appendix A

Metallurgist's Report

Investigation of the Outlet Pipe Failure Flaming Gorge Dam

Prepared for

United States Bureau of Reclamation
PO Box 25007, Denver Federal Center
D-8180
Denver, Colorado 80225

ATTN: Mr. Thomas Johnson

Order No. 1425-96-PB-81-50047

26 July 1997

Prepared by

Jim D. Mote, Ph.D., P.E.
Consulting Engineer
12011 North Antelope Trail
Parker, Colorado 80134

Introduction

Mr. Thomas Johnson, Mr. William McStraw, and I examined an outlet pipe failure at the Flaming Gorge Dam on June 30 and July 1, 1997. The onsite inspection included an inspection of the adjacent outlet pipe as well. The failed pipe had significant cavitation damage, corrosion, and erosion that resulted in catastrophic rupture. A portion of the fracture surface was removed for more detailed examination and analysis. Examination of the adjacent outlet pipe showed no cavitaion damage and no significant deterioration. This report details the results of the inspections described above as interpreted by this author.

Results of Inspection

The pipe rupture consisted of a piece of material roughly trapezoidal in shape that was torn from the pipe. The piece was about 10 inches at the small end where the fracture initiated along the heat affected zone of the weld and extended about 20 inches down stream from the weld. The piece was about 20 inches wide at the downstream termination of the rupture. Figure 1 is an overview of the fractured pipe and Figure 2 is a closer view of the region of fracture initiation along the weld heat affected zone. In all the figures, where applicable, the arrow in the upper right corner points down stream. Figure 3 is a view of a crack that extends about 6 inches into a portion of the pipe adjacent to where the piece was torn out. Figure 4 shows the region on the left side of the pipe (looking downstream) where the fracture deviates from the area near the weld into the pipe proper. Figure 5 shows an area of ragged fracture further downstream from the region shown in figure 4. Figure 6 shows an area of severe cavitation damage on the bottom of the pipe near the ring-follower gate. Figure 7 is a view of the rupture from the outside of the pipe.

Figure 8 is a view of the section that was removed from the pipe which included the major portion of the fracture surface. The piece that was torn out fitted into the U-shaped cavity of the figure. All fractographic features have been obliterated along the edge indicated by the arrow in this figure because of vibrational impacts with the missing piece of pipe. Figure 9 shows some lateral cracks viewed from the outside surface of the pipe; the significance of these cracks will be discussed later. Figure 10 shows the crack in the heat affected zone along the welds in the area adjacent to the missing piece of pipe. Figure 11 is a view of this same area after the crack was opened and shows the matching fracture surfaces. The arrow in these photographs indicates an region of possible low cycle fatigue as exhibited by the visible beach marks. Also note the extensive cavitation damage along the fracture surface visible in the upper left side of Figure 10. Figure 12 is a closer view of this damage.

Figure 13 shows some of the cavitation damage, corrosion, and erosion on the fracture surface along the bottom of the U-shaped fracture surface. On the right side the cavitation damage and corrosion appear to penetrate the complete pipe thickness. As you move to the left, erosion damage begins to appear (smooth areas) until it predominates on the left side.

Figures 14 and 15 show some of the detail of the cavitation pits in a rough polished section through the thickness of the pipe. Note the sharpness of the base of the pit in Figure 15. The bottom of this pit is about 1/4-inch from the outside surface of the pipe. Such pits are ideal locations for additional corrosion damage. It should be noted that even when the gate valve is closed there is slight leakage that would keep this surface wet thus causing corrosion to continue. Figure 16 shows some deep cavitaton pits at low magnification.

A small piece of the fracture surface was cut out in the region near one of the lateral cracks. This piece was ultrasonically cleaned in a commercial cleaner to remove the corrosion products. Figure 17 shows the through-the-plate fracture surface with the erosion grooves aligning approximately perpendicular to the pipe surface. Figure 18 ''goes around the corner'' into the region of the lateral crack. Here the erosion lines have changed direction and are nearly parallel to the pipe surface indicating a change in the direction of flow by some mechanism. Hence these cracks are just extensions of the process that caused catastrophic failure.

Microstructures

Figure 19 shows the microstructure of the material just behind the region of ragged fracture shown in Figure 5 (all micrographs are at 200X magnification). The laminar appearing fracture in this area raised the question as to whether there was internal defects in the metal. This micrograph shows clearly that such is not the case; the microstructure is typical of ASTM A285 annealed and normalized material. The white areas are ferrite and the dark areas are either fine pearlite or bainite.

Figures 20 and 21 show microstructures at the fracture surface in the vicinity of the weld. The structure is quite variable here as is expected due to the uncontrolled grain growth along the heat affected zone. The small fragment at the arrow in Figure 21 has undergone considerable plastic deformation probably due to impact with the missing piece of pipe. Figure 22 shows the heat affected zone near the fracture surface; Figure 23 is inward (toward the weld) from the area shown in Figure 22 and shows the transition structure; Figure 24 is further inward showing typical weld metal structure. All of these micrographs reveal good material and the microstructures are normal.

Figure 25 is a picture of the bottom of the outlet pipe adjacent to the failed pipe. There is no evidence of cavitation or corrosion damage. This outlet pipe appears to be structurally sound.

Discussion

Although the location of the fracture initiation cannot be identified, the probable scenario of failure is as follows:

- Sometime in the past there was cavitation damage to the bottom of the outlet pipe which extended beyond the weld between the transition piece and the first section of pipe. There may or may not have been penetration of the pipe at this time. If there was no penetration due to the initial damage, subsequent cavitation and/or corrosion in the cavitation pits would eventually produce penetration.
- Once penetration occurred, erosion ensued from the flow through the hole. This erosion caused continued crack growth along the softer heat affected zone. The weld just downstream of the weld would be expected to suffer the most cavitation damage since the weld surface is above the pipe surface. This perturbation would exacerbate the cavitation damage at this location.
- All of the physical fractographic evidence indicates a failure from cavitation, corrosion, and erosion. Pipe vibration, in addition to promoting cavitation also produced some low cycle fatigue cracking.

Conclusions

The outlet pipe distress started from cavitation damage followed by corrosion.

Subsequent to penetration, damage continued by the erosion mechanism culminating in rupture of the pipe. Severe pipe vibration augmented cavitation and produced some areas of low cycle fatigue.

No material defects in the weld metal or base material were found.

Figure 1. Overview of Fractured Pipe

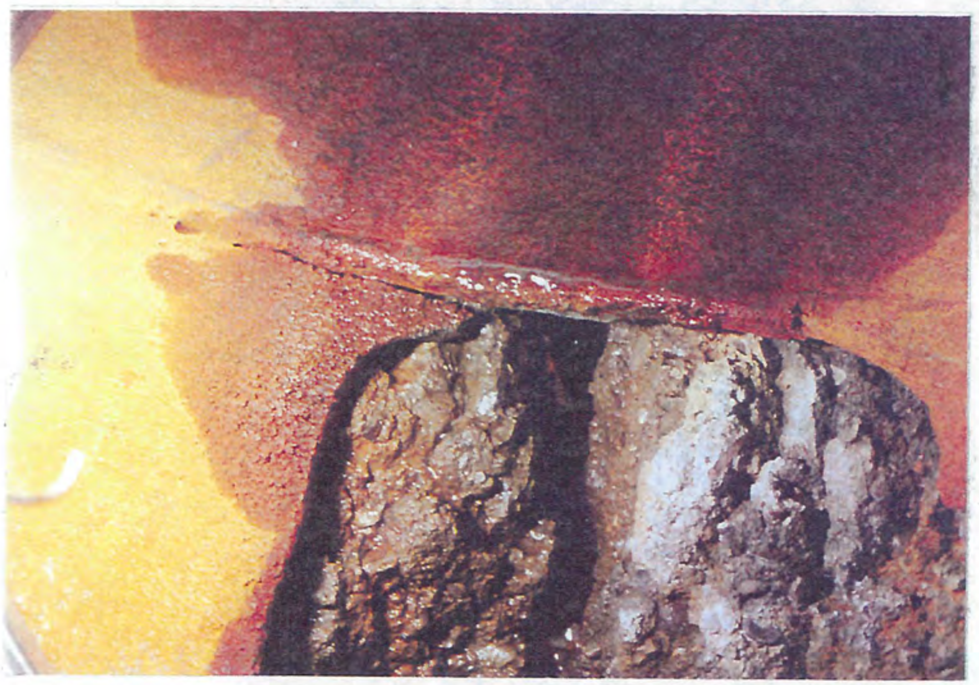


Figure 2. View of Fracture Along Weld

Figure 3. View of Extension of Fracture Adjacent to Piece Torn Out

Figure 4. Area Where Fracture Deviates From Heat Affected Zone

Figure 5. Area of Ragged Fracture

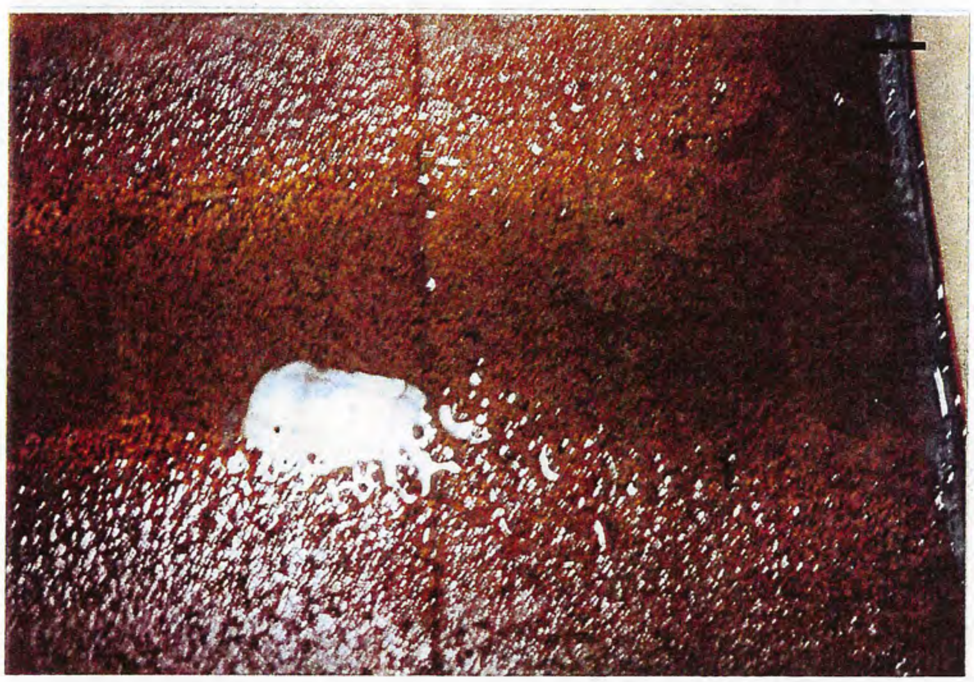


Figure 6. Area of Severe Cavitation Damage

Figure 7. Rupture Viewed From Outside Pipe

Figure 8. Section Removed From Pipe For Fractographic Examination

Figure 9. Lateral Cracking Along Fracture Surface

Figure 10. Cavitation Damage and Low Cycle Fatigue

Figure 11. Matching Fracture Surfaces of Crack of Figure 10

Figure 12. Close-up of Cavitation Damage, Interior Surface

Figure 13. Cavitation Damage, Corrosion, and Erosion; Fracture Surface

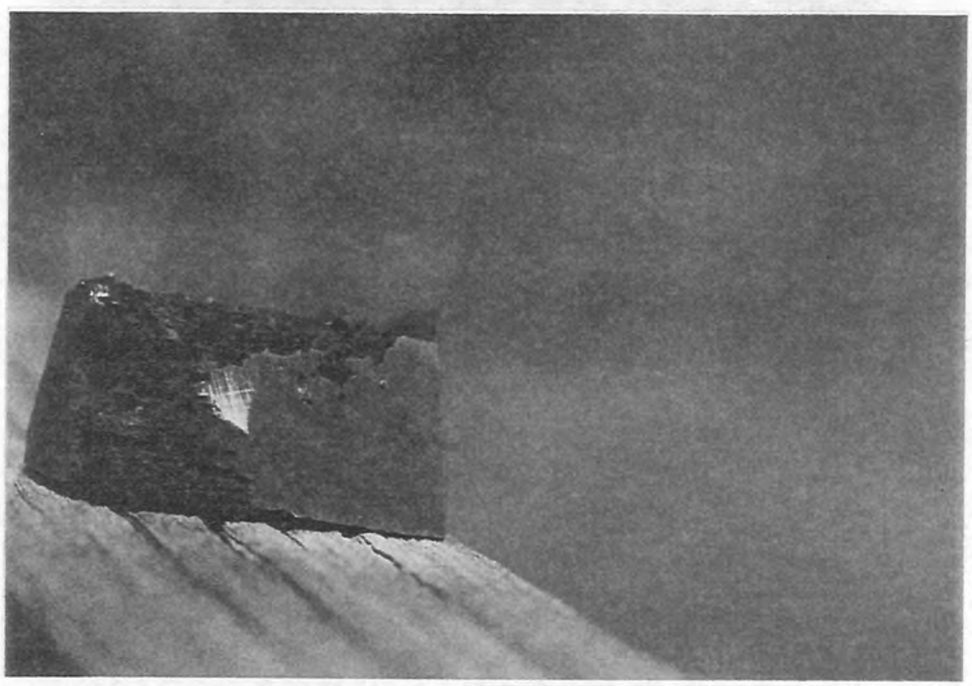


Figure 14. Polished Section Showing Depth of Cavitation Pit

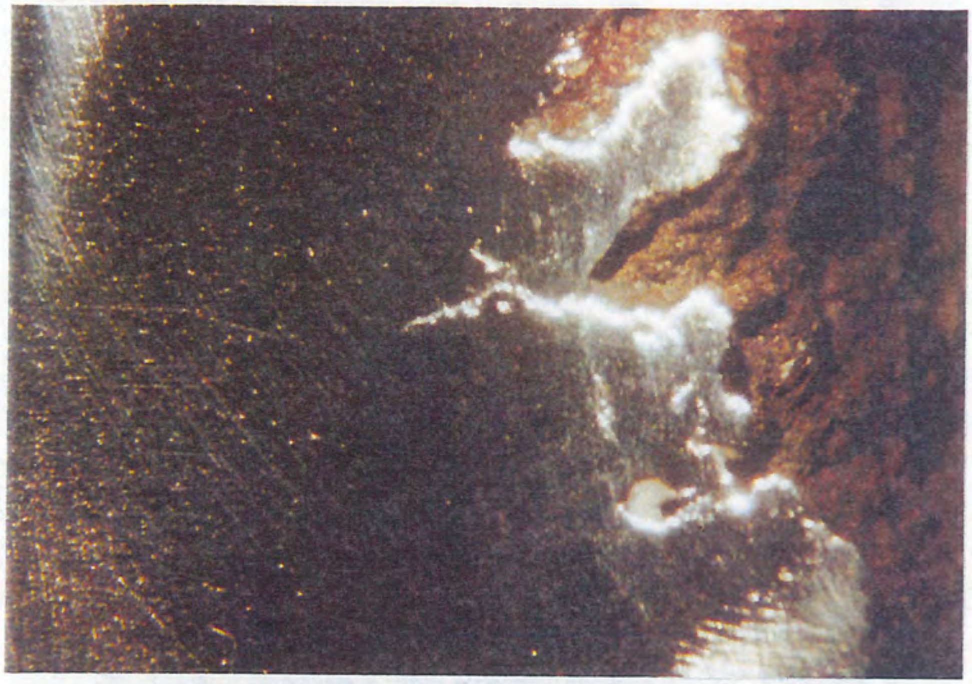


Figure 15. Cavitation Pit of Fig. 14 At Higher Magnification

Figure 16. Cavitation Pits As View From Surface

Figure 17. Erosion Through The Plate

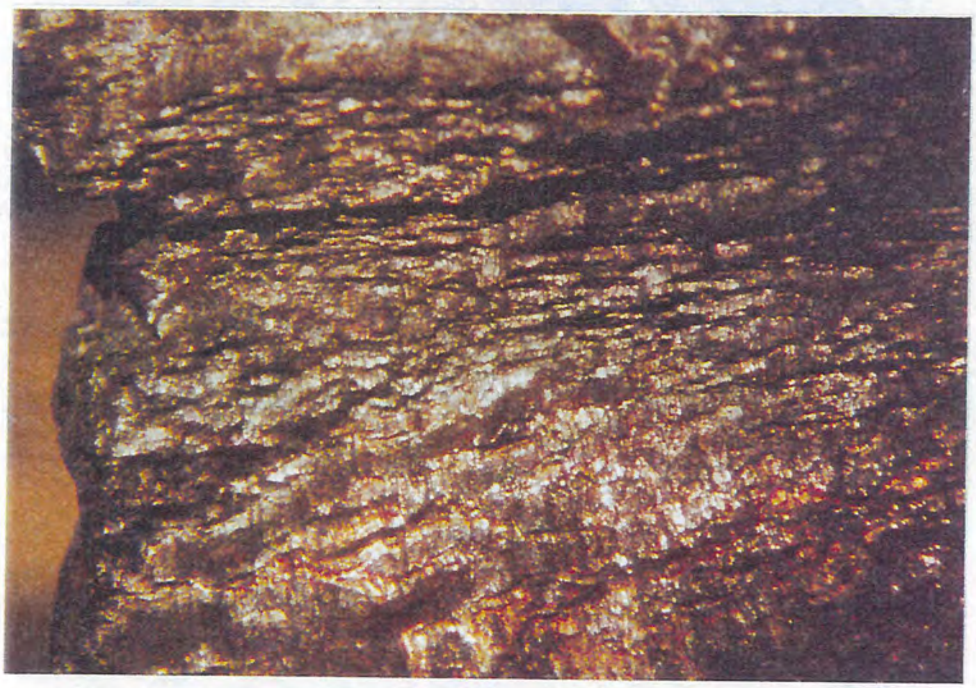


Figure 18. Lateral Erosion

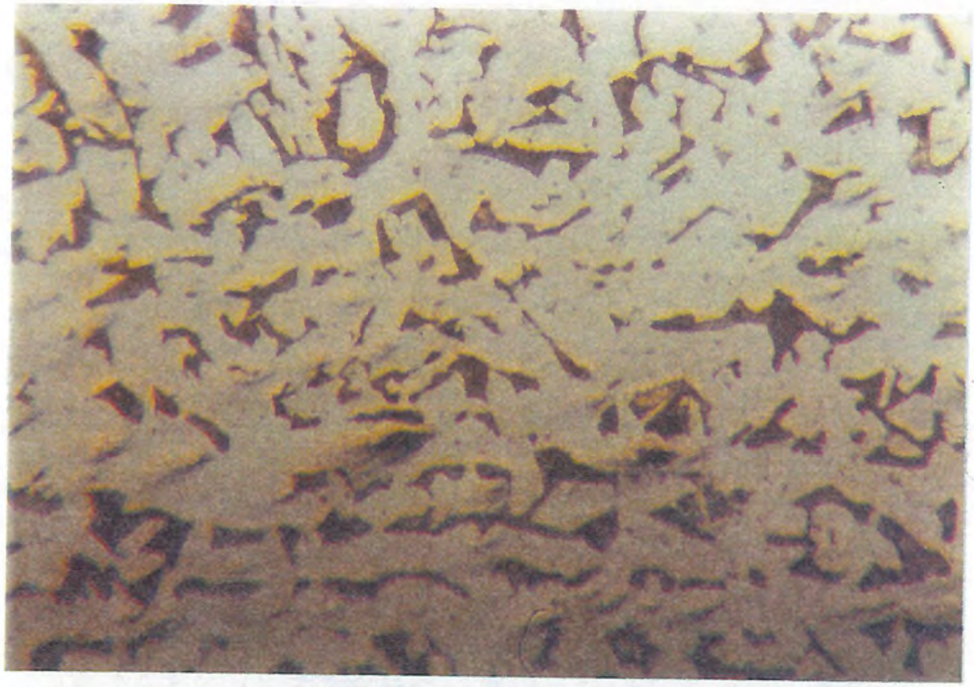


Figure 19. Microstructure, Material Behind Ragged Fracture, Figure 5 (200X)

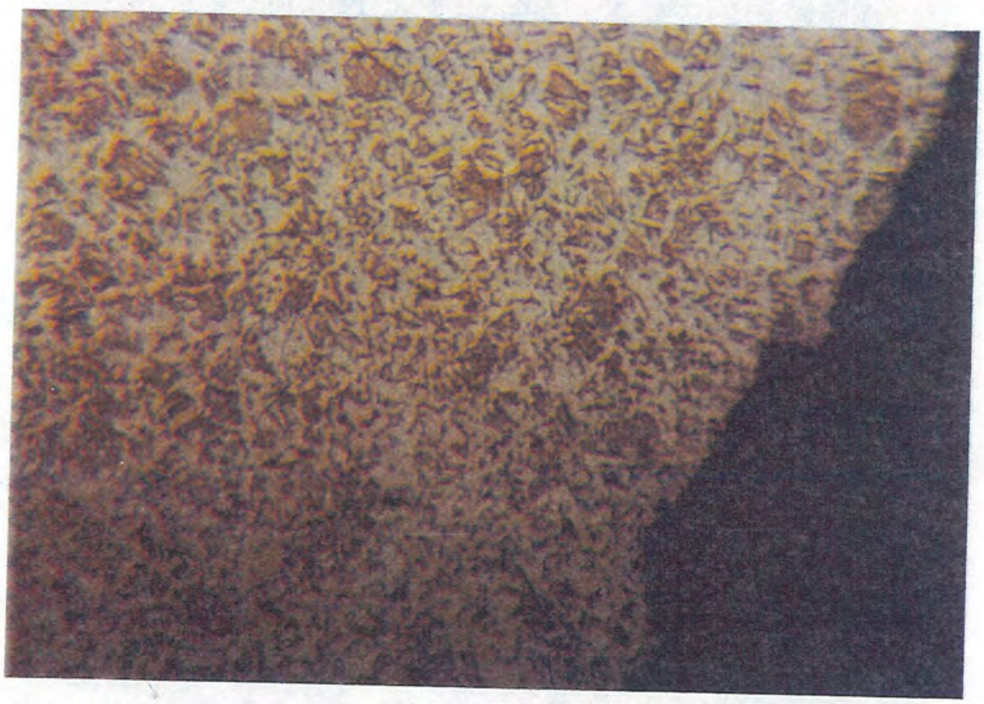


Figure 20. Microstructure at Fracture Surface

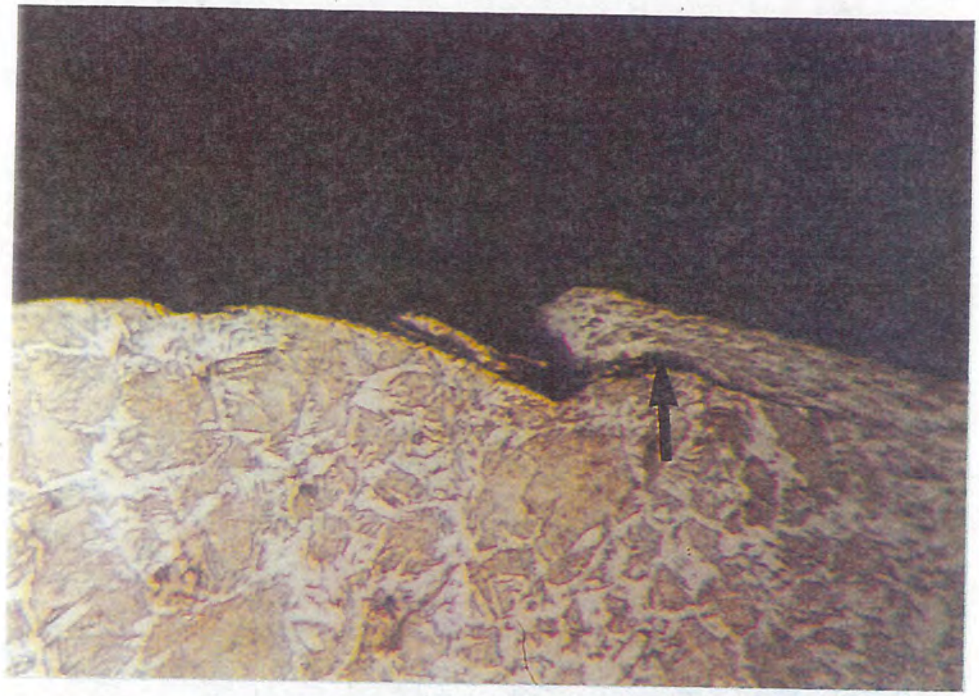


Figure 21. Microstructure At Fracture Surface, Another View (200X)

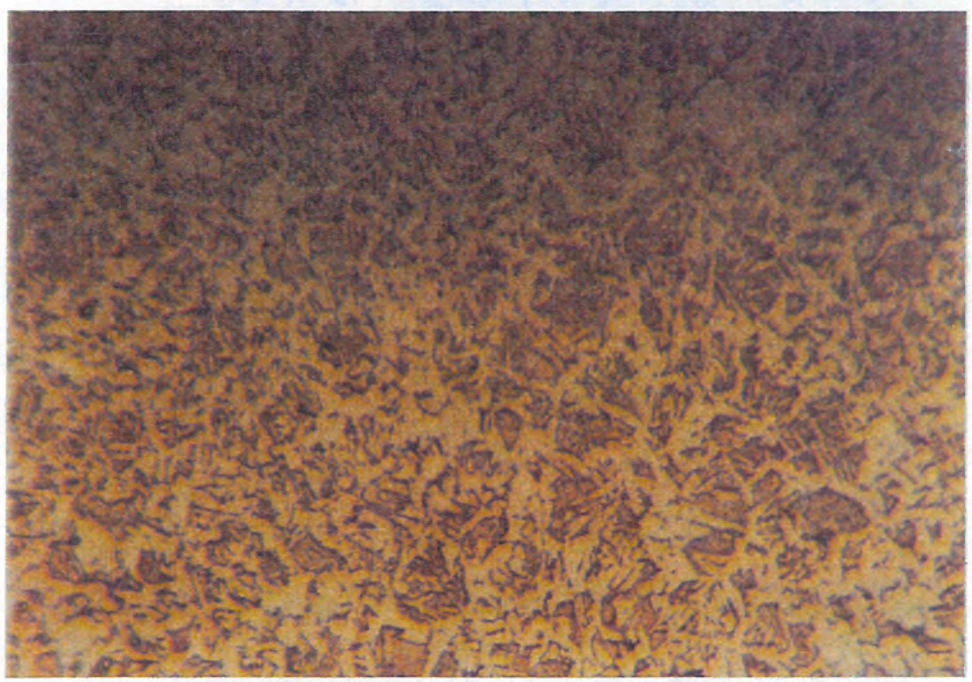


Figure 22. Microstructure, Recrystallization, Heat Affected Zone (200X)

Figure 23. Microstructure, Transition Region In Weld Metal (200X)

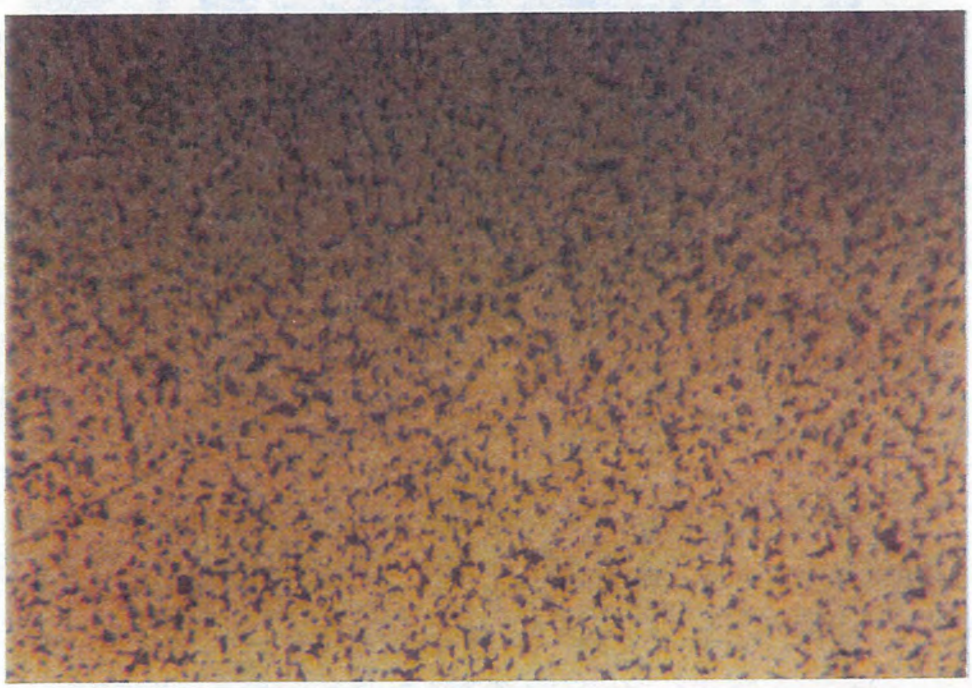


Figure 24. Microstructure, Weld Metal (200X)

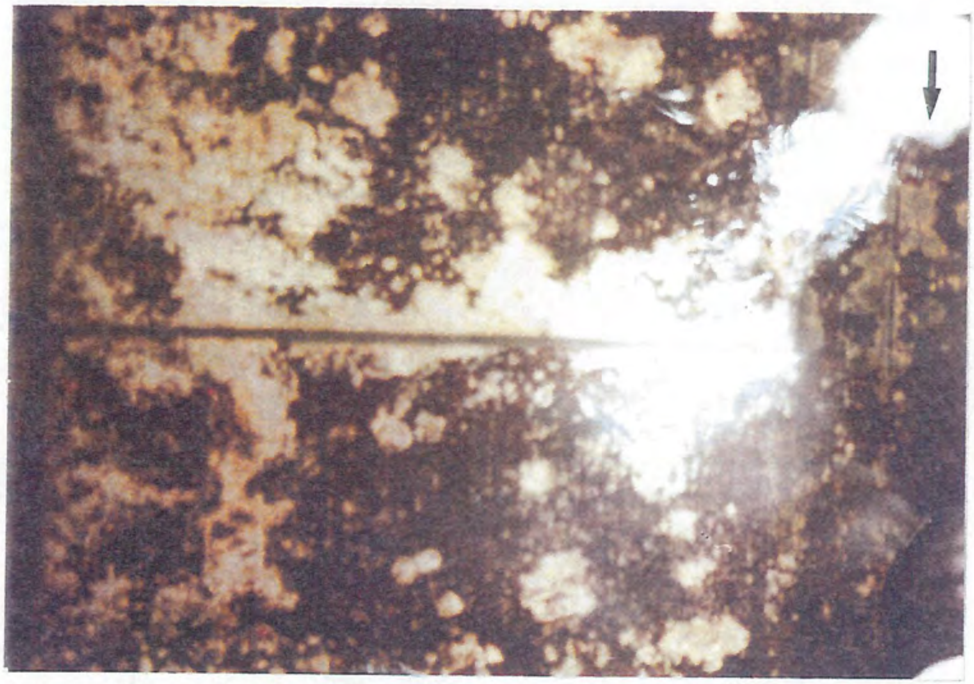


Figure 25. Bottom Inside Surface Of Adjacent Pipe

Appendix B

Structural Engineer's Report

BUREAU OF RECLAMATION
Technical Service Center
TRAVEL REPORT

Code: D-8130 **Date:** July 7, 1997

To: Dan Drake, D-8420
Team Leader

From: Dan Mares, D-8130

Subject: Flaming Gorge Dam , Colorado River Storage Project, Utah

1. Travel period: July 1 and 2, 1997

2. Places or offices visited: Flaming Gorge Dam, Rock Springs, Wyoming and vicinity.

3. Purpose of trip: To inspect and assess damage to reinforced concrete that occurred following the failure of outlet pipe no. 2.

4. Synopsis of trip: I departed Denver International Airport at 8:10 pm on July 1, 1997 for Rock Springs, Wyoming. I arrived at Flaming Gorge Dam about 9:30 am on July 2, 1997. I briefly met with Tom Welstad, Manager of the Flaming Gorge Field Division, who directed me to the powerplant. I then met with Dick Flink, Plant Maintenance Supervisor, who accompanied me to the outlet works just downstream of the 66-inch ring follower gates. We inspected outlet works pipe no. 2 which was the outlet pipe that experienced a failure on July 28, 1997. We initially inspected the exterior to the outlet works pipe and the damaged concrete. A section of steel about 18 inches by 24 inches had been removed from the invert of the pipe. Below the invert of the pipe, a portion of the concrete was damaged. The maximum dimensions of the damaged concrete were about 5.5 feet in the horizontal direction, 3 feet in the vertical direction, and 2 feet 3 inches upstream into the concrete (see figure 1). An existing vertical crack in the concrete was observed from the invert of the outlet works pipe to the 6-inch drain line. Damage to the concrete tended to follow this crack downward (see photographs 1 and 2). Some drummy concrete was noted which will need to be removed. The minimum area requiring repair was marked on the concrete surface. Some areas of spalled concrete were also noted, predominantly around the lower half of the pipe (see photograph 3). Four rows of reinforcement were exposed due to the erosion and removal of concrete. The reinforcement has a spacing of about 4 inches on center. Dick Flink indicated that the reinforcement developed rust after the bars were exposed (see photographs 4 and 5).

The inside of the pipe was then inspected. The downstream edge of the missing piece of steel pipe was right at the face of the concrete (see photograph 6). Two areas that were cut for testing are shown at the top of the photograph., A blue crowbar is supporting one side of the cut pipe.

Some clear plastic pipes are also shown on the photograph that are being used to remove water leaking from the ring follower gate. Some pitting and corrosion are evident on the upper right side of the photograph. The pitting appears to be caused by cavitation.

5. Conclusions: Repairs to the outlet works concrete and pipe are currently planned. Additional concrete will need to be removed to facilitate repairs to the steel pipe. A minimum 1-inch saw cuts should be used around the perimeter of the damaged area; however, a deeper saw cut may be used to facilitate concrete excavation. All drummy concrete should be removed. The rust on the reinforcement should be removed prior to the placement of concrete. Hooked #6 dowel bars will be included in any proposed repair to tie the existing concrete to the new concrete. It is also anticipated that some grouting may be required to fill voids in the replacement concrete.

6. Action correspondence initiated or required: None

Attachments

cc: Regional Director, Salt Lake City UT,
Attn: US-100
Manager, Flaming Gorge Field Division,
Dutch John UT, Attn: FG-100 (Welstad)
bc: D-8000 (Cook), D-8130 (Mares, Trojanowski), D-8450 (McStraw), D-8420 (Arrington), D-8470 (Bortz)

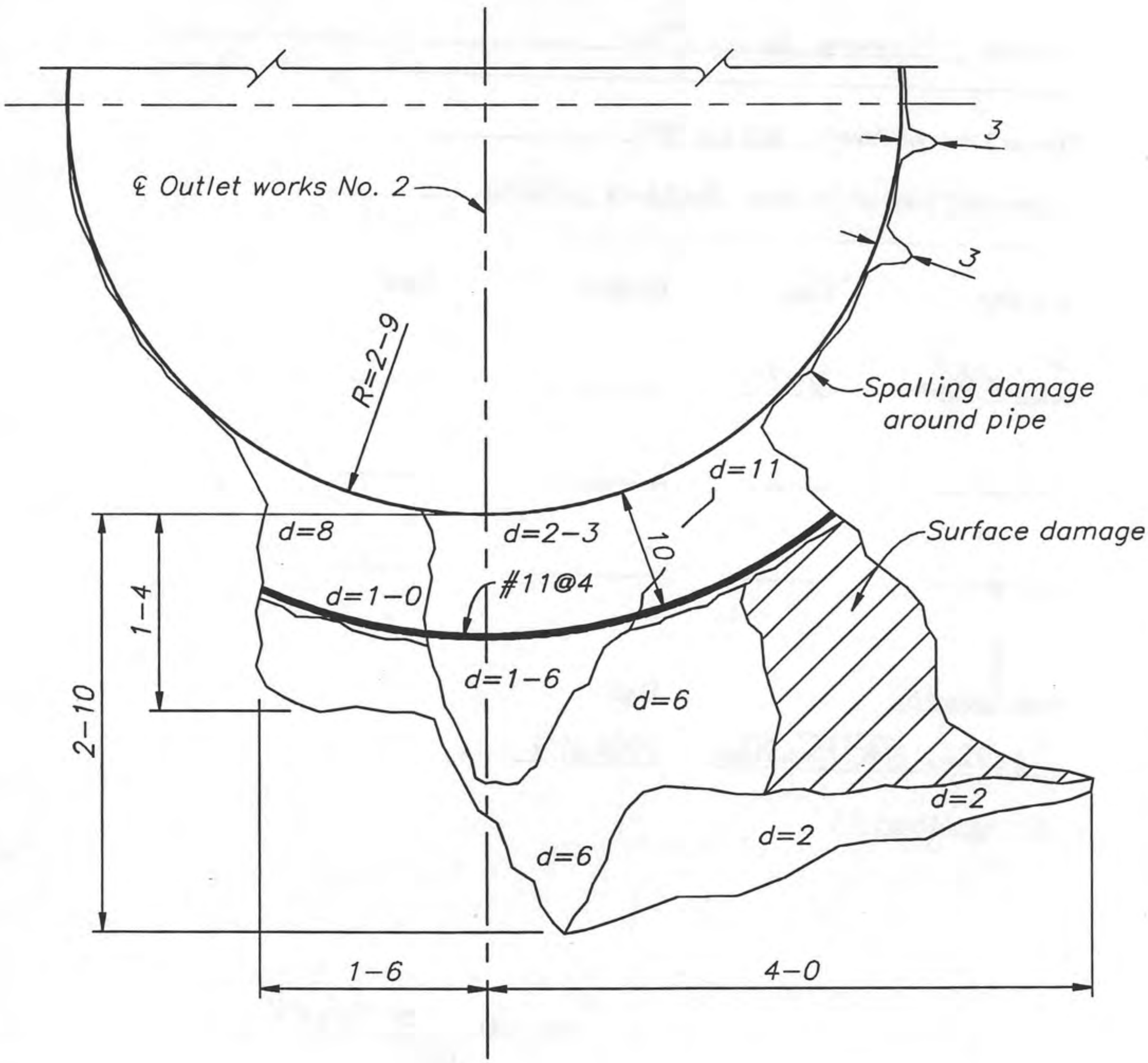


Figure 1. – Schematic showing approximate dimensions and depths of damage in the concrete.

SIGNATURES AND SURNAMES FOR:

Travel to: Flaming Gorge Dam

Date or Dates of Travel: July 1-2, 1997

Names and Codes of Travelers: Dan Mares (D-8130)

Travelers	Date	Travelers	Date
Dan Mares	7/16/97		

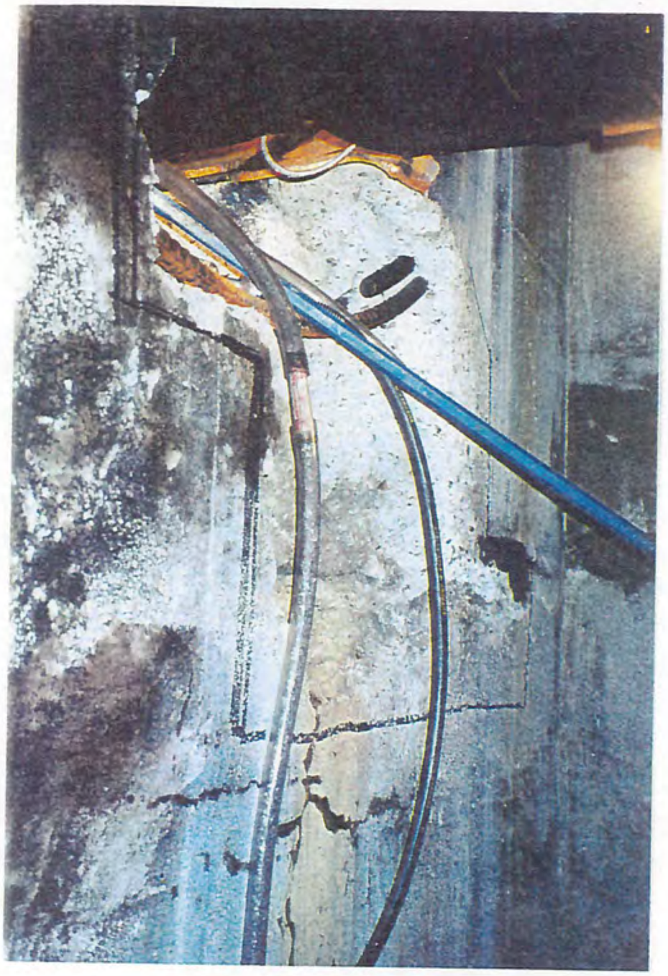
Peer Review by: William R. Fiedler

Date 7/16/97

Noted and Dated By:

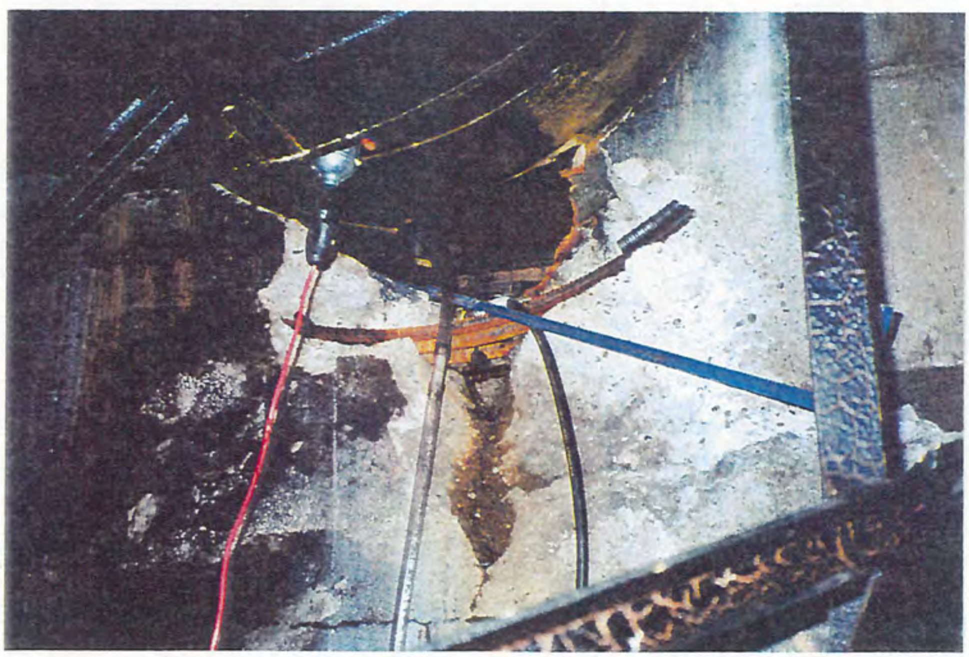
NOTED 07-16-97
(Date)

Chuck Cooper Acting
Group Manager, Waterways & Concrete Dams



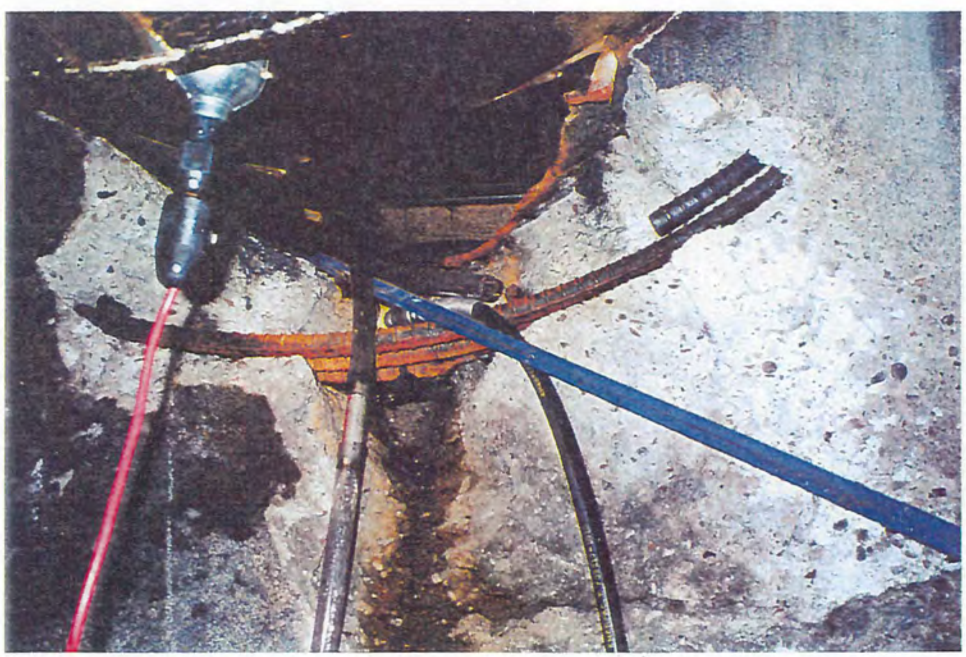
Photograph No. 1. - Showing bottom of outlet works pipe and extent of damaged concrete.

Photograph No. 2. - Showing damaged outlet pipe and concrete.

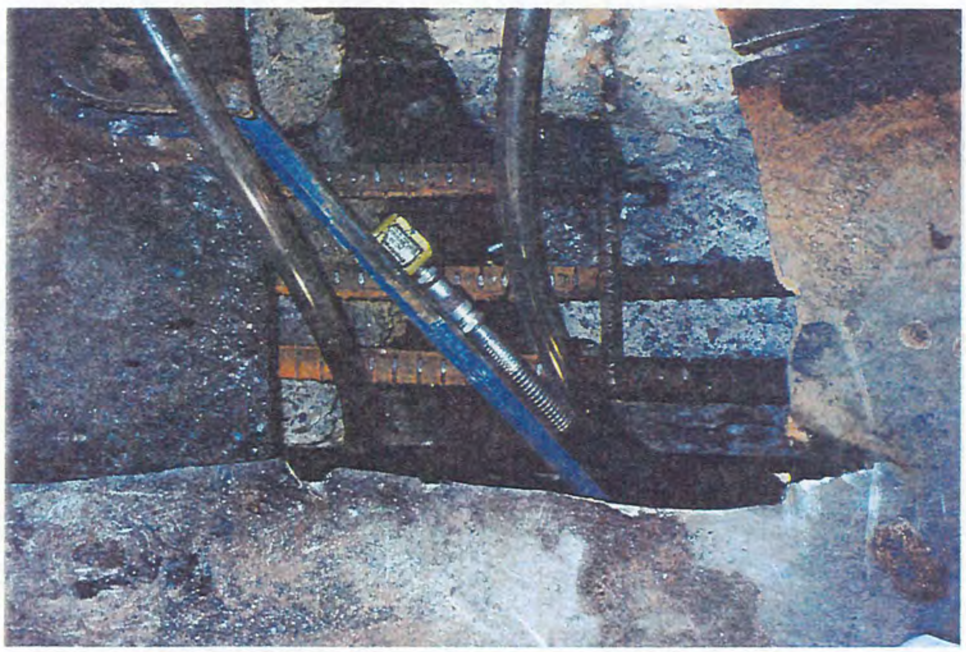


Photograph No. 3. - Note spalling around the outlet pipe.

Photograph No. 4. - Showing damaged concrete and rust on reinforcement.



Photograph No. 5. - Showing damaged concrete and rust on reinforcement.



Photograph No. 6. - Flow is from top to bottom. Shown is the invert looking downward from the inside of the outlet works pipe.

Appendix C

Reference Data (SOP, DOC, O&M Review Report)

SOP

CHAPTER II

ELECTRICAL, MECHANICAL, AND STRUCTURAL

A. GENERAL DESCRIPTION OF DAM

Flaming Gorge Dam

Location:	-Latitude	40° 54' 50" N
	-Longitude	109° 25' 16" W

Type:	Concrete thin arch
Structural height:	502 ft.
Top width:	27 ft.
Maximum base width:	131 ft.
Crest length:	1,285 ft.
Crest elevation:	6,047 ft.
Volume:	986,000 cubic yards

Spillway - The spillway is a concrete-lined tunnel which extends 675 feet through the left abutment. The control structure to the spillway consists of 2 - 16' 9" by 34' hydraulically-operated fixed-wheel gates. The first 75 feet below the fixed-wheel gates is an open concrete transition down to the 26' 6" diameter opening to the concrete-lined tunnel. The next 182 feet of the tunnel drops on a 55 degree incline from horizontal, necks down to a diameter of 18 feet, and enters a transition zone. The next 161 feet is the transition zone (an elbow) in which the tunnel changes to a slope of 0.01 ft/ft. The spillway crest elevation at the intake structure is 6006.0 feet. The maximum capacity of the spillway tunnel is 28,800 ft^3/s.

River Outlet Works - The outlet works through the dam consists of two 72 inch steel pipes, which reduce to 66 inches at the two ring-follower gates and continue downstream to the two 66-inch hollow-jet valves. The discharge is directed into the river channel downstream from the powerplant tailrace. The maximum discharge of the two outlets is 4,000 ft^3/s at maximum water surface elevation 6,045 feet.

Powerplant - The powerplant is located at the toe of the dam. The powerplant contains three turbines and generators with a capacity of 51,500 kilowatts each with a maximum head of 440 feet. Three 10-foot-diameter steel-lined penstocks are located in the central part of the dam each serving one of the 50,000-horsepower turbines. The powerplant began operation in 1963.

B. *SOP COORDINATION WITH DOC*

The DOC entitled "Flaming Gorge Dam, Colorado River Storage Project, Utah" in addition to the manufacturer's instructions on certain equipment adequately describe the O&M procedures for Flaming Gorge Dam and shall be considered an essential part of this SOP.

Operation of the spillway, river outlets and other plant equipment is described in detail in Chapter 5 (Power Facilities Operation), section K, of this SOP.

Captioned photographs in Appendix A are provided to assist the operator in identifying electrical, hydraulic, and mechanical equipment described in the DOC.

C. *SPECIAL INSTRUCTIONS*

Conformance to special instructions is important for the continuing safety and economical operation of the equipment and structures. The following are instructions and procedures which will be followed:

1. **Spillway and Spillway Gates -** Water will not be allowed to flow over the top of the spillway gates. The river outlets will be operated to their full capacity before the spillway is placed into service. If the reservoir has reached its full capacity at elevation 6040 feet and the river outlets are operated at full capacity, the spillway gates will be operated to bypass the excessive inflow.

   To insure proper flow and direction of water into the spillway tunnel, the spillway gates are to be operated simultaneously with equal gate openings.

2. **River Outlet Works -** The ring follower gates are to be operated at either 100 percent open or kept fully closed. They should not be operated at partial gate openings. The regulation of flow is to be accomplished by the hollow jet valves. For releases above 500 cfs through the river outlets, the bypass should be divided equally between the two river outlets.

3. **Ventilation System -** All ventilating fans in the dam and powerplant should be operated continuously except for unusual conditions such as: extremely cold weather or for equipment maintenance.

4. **Test Operating of Equipment -** Annually the operation of the spillway gates will be tested. If the reservoir elevation is above the crest of the spillway (6006 feet), the gates will be opened one at a time to about 4 to 6 inches and re-closed.

   Note: If a gate fails to close property or fails to seat, stop the test immediately, determine and correct the problem. Contact the responsible Bureau office before further testing.

   If the reservoir elevation is below elevation 6006, the gates will be opened to 100 percent and re-closed to exercise the mechanism, rollers, etc.

   Annually the operation of the river outlet works will be tested by watering up the river outlet conduit and operating the ring follower gates to 100 percent. After the ring follower gates are closed and during the unwatering process, the hollow jet valves will be opened to 100 percent and then restored to the normal opening of 13 percent. This can be accomplished without bypassing water if necessary. See procedure in Chapter V of this SOP.

Revised: April 19, 1993

SECTION K

MAJOR DAM EQUIPMENT AND AUXILIARIES

RIVER OUTLET WORKS

GENERAL

Two 72 inch diameter steel outlet pipes extend from the trashrack protected intake structure on the upstream face of the dam, through the dam to two 66 inch ring follower gates and the down-stream toe of the dam. The outlet pipes reduce to 66 inch diameter just upstream from the ring follower gates. A 7 3/4 X 7 3/4 foot bulkhead gate is provided to close either river outlet intake on the face of the dam, to unwater the outlet pipes. Downstream from the ring follower gates the the 66 inch outlet pipes continue to two 66 inch hollow jet valves. The outlet pipes are about 210 feet long between the intake and the ring follower gate and about 200 feet between the ring follower gates and the hollow jet valves. The outlet pipes drop 113 1/2 feet from intake elevation 5743 to elevation 5629.50 at the ring follower gates and another 14 1/2 feet to the hollow jet valves at elevation 5615. Two 6 inch air vent pipes extend upward from the outlet pipes at the intake to the upstream face of the dam, just below the top. These vents allow air to escape or enter when filling or unwatering either outlet pipe upstream of the ring follower gate. A 6 inch standby water line extends from each of the outlet pipes to gate valves in the powerplant and are used for the fire water supply. Bypass piping at the ring follower gates provides for filling the outlet pipes. A 10 inch diameter air vent pipe enters the downstream side of each ring follower gate. When filling the outlet pipes downstream from the ring follower gate, 2 inch vent valves, from each 10 inch air vent pipe, must be manually opened. When unwatering the 10 inch check valves allow air to enter. The bypass pipes at the ring follower gates are equipped with 6 inch valves at each upstream and down-stream connection. A 6 inch line containing a gate valve interconnects the two bypass pipes so that water from either outlet pipe may be used to fill the other outlet pipe to reservoir level. The bypass system also allows filling the sections of outlet pipe downstream from the ring follower gates. The intake bulkhead gate is installed with the gantry crane.

The two 66 inch ring follower gates are located in the river outlet structure at elevation 5638.50 on the downstream side of the dam. They normally operate with a balanced head but may be required to close under full flow conditions if the hollow jet valves become inoperable. They are also required to open with an unbalanced head if the three generators are shutdown by relay action. The hollow jet valves are preset at 12% to supply 400 cfs in the river. The ring follower gates will always be fully open or fully closed. The control cabinet is adjacent to the valves in the river outlet structure. Remote control is not provided. The gates are a slide type with a body, bonnet, leaf with a ring follower, and hydraulic hoist. Bronze seats form the sliding and sealing surface which contacts the downstream stainless steel clad skinplate of the leaf and ring follower unit. Grease fittings are provided for lubricating the sliding surfaces of the seals and seats. The hoist is an oil operated cylinder supported on the bonnet cover and is coupled to the leaf and ring follower units by the piston stem. The piston has both packing and piston rings, is 18 inches in diameter, and has a nominal stroke of 5 feet 11 inches. A gate position indicator is attached to the hoist.

The hollow jet valves are bolted to the upstream flange of the outlet pipes. Both valves are operated from a common control cabinet located on a concrete platform above the valves. The valves must be operated locally. Remote operation is not provided. The hollow jet valve is of welded and cast steel construction and consists basically of a body and a needle which is moved axially by oil pressure to control the flow of water. The needle is mounted on a plunger which is received and guided by an oil cylinder located on the longitudinal centerline of the valve. The cylinder is positioned in the body by six radial splitters. The needle has a travel of 23 inches and moves upstream to close the valve. As the valve is opened, water flows past the periphery of the needle in the shape of a cylindrical ring along the inside of the valve body. The splitters which support the needle, cut the ring into sectors and the water discharges from the valve in six separate jets.

In order to maintain a constant minimum flow (400 cfs) in the river, the river outlets have been modified as follows to open automatically if the units are tripped or all three wicket gates go to speed no load position or below: A wicket gate position cam switch on units no. 1, 2, and 3 have been wired in series to initiate the opening of the ring follower gates if the wicket gates close by starting a 10 minute timer. When the gates close the timer is started and an alarm will sound at Flaming Gorge and the Glen Canyon Control Center (Ring Follower Gate Emergency Open). When the timer times out, the ring follower gate which has been set up for auto opening will start to open. When the gate is fully open a limit switch will shut off the pumps.
The corresponding hollow jet valve is preset to release 400 cfs, about 12 to 13 % open. Normally the no. 1 river outlet will be used.
A bypass switch is installed in the circuit and is located in the front of each actuator cabinet. This switch should be closed on any unit which is unwatered for maintenance and the wicket gates are in the open position.

COMPONENTS AND DESCRIPTIONS

Operation

1. **Watering up (filling) the upstream outlet pipe.**

    a. Check closed or close the 66 inch ring follower gate valve.

    b. Open the upstream filling valve on the empty outlet pipe.

    c. Open the valve in the interconnecting line.

    d. Open the upstream filling valve on the full outlet pipe.

    e. When the outlet pipe is full, the bulkhead gate may be removed with the gantry crane.

    f. Close the three filling valves.

2. **Watering up the downstream outlet pipe.**

   a. Check closed or close the 66 inch hollow jet valve.

   b. Open the 2 inch air vent valve.

   c. Open the downstream and upstream filling valves in that order.

   Note - Either of the the full upstream outlet pipes can be used by opening the upstream interconnecting valve.

   d. When the outlet pipe is full water will flow out of the 2 inch air vent valve. Close the air vent valve.

   e. The 66 inch ring follower gate may now be opened under balanced head.

3. **Unwatering the upstream outlet pipes.**

   a. The 66 inch ring follower gate valve should be open with the downstream pipe watered up and the 66 inch hollow jet valve closed.

   b. Install the bulkhead gate using the gantry crane.

   c. Open the hollow jet valve slightly, to slowly drain the outlet pipe. Air will enter the outlet pipe through the 10 inch check valve and line.

4. **Steps to open the 66 inch ring follower gate valves.**

   a. Check the down stream outlet pipe watered up and the hollow jet valve closed.

   b. Open hydraulic valves J and K for no. 1 gate or L and M for no. 2 gate.

   c. Shift 4 way valve to the open position.

   d. Place selector switch to no. 1 or no. 2 position (depending on which gate is being opened).

   e. Start hydraulic pumps by depressing start button.

   f. When fully open a pressure switch will turn pumps off.

   g. Place 4 way valve to neutral position.

   h. Close hydraulic valves J and K or L and M.

5. **Steps to close the 66 inch ring follower gate valves.**

   a. Check closed or close corresponding hollow jet valve.

   b. Place selector switch to position 1 or 2 (depending on which valve is being closed).

   c. Open hydraulic valves J and K for valve no 1 or L and M for valve no. 2.

   d. Place 4 way valve in close position.

   e. Depress close button (hold until gate has dropped below limit switch).

   f. Start pumps.

   g. After the gate is fully closed and pumps have shut off shift the 4 way valve to neutral position.

   h. Close hydraulic valves J and K or L and M.

6. **Steps to open 66 inch hollow jet valves.**

   a. Open hydraulic valves A and B for valve no. 1 or C and D for valve no. 2.

   b. Shift 4 way valve to open position.

   c. Start pumps.

   d. When valve is in the desired open position shift 4 way valve to neutral position and turn off pumps.

   e. Close hydraulic valves A and B or C and D.

   Note - To close use same procedure except shift 4 way valve to close position.

7. **Procedure to set up no. 1 ring follower gate for automatic opening.**

   At the hollow jet valve cabinet.

   a. Open no. 1 hollow jet valve to 12 or 13 % (400 cfs).

   b. Close shutoff valves A and B.

   c. Check closed valves C and D.

   d. Place 4 way valve in neutral position.

At ring follower gate control cabinet.

a. Check all power supply breakers closed.

b. Place selector switch to no. 1 position.

c. Open hydraulic valves J and K.

d. Check closed hydraulic valves L and M.

e. Shift 4 way valve to open position.

f. Check or place warning alarm switch to "auto".

To close after an automatic operation use procedure no. 5 above.

Releases Through The River Outlet Works

When bypassing water through the river outlet works at a rate of 1,000 cfs or more, the flow should be divided equally between the two hollow jet valves.

Checks And Tests

annually:

The following procedure is to be conducted annually and will exercise the ring follower gate valves, hollow jet valves and test the automatic operation of the ring follower gates.

1. Close no. 1 and no. 2 hollow jet valves.

2. Open the down stream vent valve and water up no. 1 river outlet pipe by opening the upstream and downstream filling valves.

3. When the downstream outlet pipe is full between the ring follower gate and hollow jet valve, close the vent valve and set no. 1 gate up for automatic opening.

4. Turn warning alarm off.

5. Notify Glen Canyon Control Center of test.

6. Close all three unit ring follower gate control switches (gate position cam switch by-pass switch located near terminal blocks in A1A, A2A and A3A).

7. Check timer operation with a stop watch. Start clock when the last by-

pass switch is closed and time until the ring follower gate starts to open.

8. Open all three unit ring follower gate control switches.

9. After the no. 1 ring follower gate has fully opened re-close the gate.

10. Close the filling valves.

11. Open no. 1 hollow jet valve to 13% to drain outlet pipe.

12. Proceed to water up and test no. 2 river outlet using the same procedure as with no. 1.

13. After tests on the ring follower gates are completed, exercise the hollow jet valves by opening them to 100% and reclosing them to 13%.

14. Set up no. 1 or no. 2 ring follower gate for automatic operation.

Power

Power is supplied to the ring follower gates and hollow jet valves from 480 vac panel PDG, breaker no. 1 for the ring follower gates and breaker no. 7 for the hollow jet valves. Power panel PDG is supplied from breaker no. 10 in MSB.

Clearance Procedures

For Clearance procedures see section "L" on Clearance procedures.

Alarms

a. Ring follower gate open.
b. River flow below minimum.

REFERENCES

Station D.O.C., located in the control room book case.

Drawings

591-D-159, 591-D-162, 591-D-168, 591-D-369, 591-D-375, 591-D-659, 591-D-835, 591-D-922, 591-D-923, 591-D-1032, 591-D-1038, 591-D-1039 and 591-D-1087.

DOC

CHAPTER IV. RIVER OUTLET WORKS

23. General

A plan, profile and sections of the river outlet works are shown on Drawing No. 46 (591-D-159). Two 72-inch-diameter steel outlet pipes extend from the trashrack protected intake structure, on the upstream face of the dam, through the dam to two 66-inch ring-follower gates at the downstream toe of the dam. The outlet pipes reduce to 66-inch diameter just upstream from the ring-follower gates. A 7.75- by 7.75-foot bulkhead gate is provided to close either river outlet intake on the face of the dam, to unwater the outlet pipes. The ice-prevention air system for the river outlet intake is described in Chapter VI, page 31. Downstream from the ring-follower gates the 66-inch outlet pipes continue to two 66-inch hollow-jet valves. The outlet pipes are about 210 feet long between the intake and the ring-follower gate and about 200 feet between the ring-follower gates and the hollow-jet valves. The outlet pipes drop 113.5 feet from intake elevation 5743.0 to elevation 5629.50 at the ring-follower gates. The outlet pipes drop another 14.5 feet to the hollow-jet valves at elevation 5615.0. As shown on Drawing No. 47 (591-D-168), two 6-inch air vent pipes extend upward from the outlet pipes at the intake to the upstream face of the dam, just below the top. These vents allow air to escape or enter when filling or unwatering either outlet pipe upstream from the ring-follower gate. Manholes are provided from the access gallery for entering the outlet pipes. See Drawing No. 46 (591-D-159). A 6-inch standby waterline extends from each of the outlet pipes to gate valves in the powerplant as shown on Drawing No. 48 (591-D-162).

Bypass piping at the ring-follower gates, as shown on Drawing No. 49 (591-D-659), provides for filling the outlet pipes. A 10-inch-diameter air vent pipe enters the downstream side of each ring-follower gate. When filling the outlet pipes downstream from the ring-follower gate, 2-inch air vent valves, from each 10-inch air vent pipe, must be manually opened. When unwatering the 10-inch check valves allow air to enter.

The bypass pipes at the ring-follower gates are equipped with 6-inch valves at each upstream and downstream connection. A 6-inch line containing a gate valve interconnects the two bypass pipes so that water from either outlet pipe may be used to fill the other outlet pipe to reservoir level. The bypass system also allows filling the sections of outlet pipe downstream from the ring-follower gates.

24. Bulkhead for River Outlet Intakes

a. Purpose.--A 7.75- by 7.75-foot bulkhead gate is provided to close the intake, on the face of the dam, of either of the two river outlets. The gate is used for unwatering the river outlets.

b. Description.--The bulkhead gate is stored on top of the dam at the gate erection mast. When required, it is installed by means of a lifting frame and the gantry crane. Installation and assembly details are shown on Drawing No. 50 (591-D-369).

(1) Gate. --The gate is a flat, structural-steel assembly with rubber seals mounted on the downstream skinplate. The seals prevent leakage by contacting seal seats embedded in concrete on the downstream side of the gate. Seals on each side of the gate bear against seats on frames embedded in concrete on the downstream face of the gate slot. Lateral movement of the unloaded gate is controlled by means of guide shoes on each side of the gate which engage guides embedded in the concrete on the face of the dam.

c. Operating data. --To close the gate, attach the gantry crane hook to the lifting frame. Using the lifting frame, pick up the gate from storage and place it in position on top of the dam. Stop the flow through the river outlet by closing the 66-inch ring-follower gate or the 66-inch hollow-jet valve. Lower the gate into the guide slots until it comes to rest on its brackets in the closed position. The gantry crane operator can then release the lifting frame from the gate, making the gantry crane available for other service. See gate handling and storage on Drawings No. 50 (591-D-369) and 51 (591-D-375).

To open the gate, the outlet conduit must first be filled to reservoir head. Close the 66-inch ring-follower gate or hollow-jet valve and fill the pipe adjacent to the gate through the 6-inch filling line provided for this purpose as shown on Drawing No. 49 (591-D-659). Then connect the lifting frame to the gantry crane hook, lower into guide slots until grappling hook engages the gate stem. Raise the gate with the gantry crane and return it to storage.

d. Maintenance. --The gate should be inspected annually and shall be painted as required. Some provision should be made to protect the seating surfaces on the gate and the rubber seals while the gate is in storage.

The weights of the two major components which require handling are:

(1) Gate.....................................27,800 pounds

(2) Lifting frame.......................... 5,400 pounds

25. Sixty-six-inch Ring-follower Gates and Controls

a. Purpose. --The two 66-inch ring-follower gates and controls will normally be required to operate under no-flow conditions to provide a tight shutoff when the hollow-jet valves are not in use, or when the conduit or hollow-jet valves are being inspected or serviced. The gates may also be required to close under full flow in an emergency if the hollow-jet valves become inoperable.

b. Description. --The two 66-inch ring-follower gates with one control cabinet are located in the river outlet structure at elevation 5638.50 on the downstream side of the dam. The gate bodies are embedded in concrete and form a part of the outlet pipes. Installation and assembly details are shown on Drawings No. 591-D-835, -836, -837, -1082, and -1084, of which Drawing No. 52 (591-D-835) is included as a part of these criteria.

(1) Gates.--The gates are a slide type with a body, bonnet, leaf with a ring follower, and a hydraulic hoist. Bronze seats and guides are attached to the downstream body. The bronze seats form the sliding and sealing surface which contacts the downstream stainless steel clad skinplate of the leaf and ring-follower unit. Grease fittings are provided for lubricating and sliding surfaces of the seals and seats. The hoist is an oil-operated cylinder supported on the bonnet cover and is coupled to the leaf and ring-follower unit by the piston stem. The piston has both packing and piston rings, is 18 inches in diameter, and has a nominal stroke of 5 feet 11 inches. A gate position indicator is attached to the hoist.

The gates were furnished by the Bethlehem Foundry & Machine Company of Bethlehem, Pennsylvania, under Invitation No. DS-5382.

(2) Control.--The control cabinet contains the hydraulic and electrical equipment for operating the two gates, and was furnished by the Baker Engineering Company, Inc., of Wichita, Kansas, under Invitation No. DS-5720.

c. Operating data.--Operating and servicing instructions and general information are given on Drawing No. 53 (591-D-1087). The gates are designed to operate under a maximum reservoir head of 415 feet. The hoist and hydraulic control system are designed to operate at a maximum oil pressure of 2,000 pounds per square inch, however, normal operating pressure will be approximately 1,750 pounds per square inch. The bypass valves are for filling the downstream pipes before opening the gates.

The manual hanger in the upper cylinder head of each hoist should be engaged for installation and maintenance operations. The hanger may also be used to hold the gates in the open position for extended periods of time.

The controls are designed to operate the gates, by manual valve selection and pushbuttons, from the control cabinet. Remote control was not provided. Two motor-pump units are provided in the control cabinet and normally both pumps are used to operate each gate; however, if one pump is inoperative, the other pump will open or close either gate in twice the normal operating time.

Normal opening time is approximately 5 minutes and closing time is approximately 6 minutes.

d. Maintenance.--A regular schedule of operating tests, inspection and maintenance should be established. A test of both gates, hoists, and the controls should be made as soon as a significant head on the gate is available and at least once a year thereafter.

Regular inspections of the hoists and controls where access is possible, should be made annually. The leaf and ring-follower unit should be removed from the embedded body of one of the gates and inspected after 5 years of operation. Particular attention should be paid to the bronze seats and clad skinplate surfaces. This inspection should be used to determine the schedule of future inspection and maintenance. Painting of the exposed parts of the gates, hoists, and controls should be scheduled as indicated by the regular annual inspections. The leaf and ring-follower unit should be painted, if required, whenever the leaf is raised for inspection.

Weights of the major parts which might require handling during maintenance or repair are as follows:

(1) Upper cylinder head assembly, only ...... 915 pounds

(2) Hoist and bonnet cover assembly .... 11,000 pounds

(3) Leaf .... 7,600 pounds

(4) Piston gland .... 45 pounds

26. Sixty-six-inch Hollow-jet Valves and Controls

a. Purpose. --Two 66-inch hollow-jet valves are used to regulate the flow of water from the river outlets. The control system is used to operate the valves.

b. Description. --Installation and details of the hollow-jet valves and the hydraulic control system are shown on Drawings No. 54 (591-D-922), 55 (591-D-923), 56 (591-D-1032), and 57 (591-D-1038). A hollow-jet valve is bolted to the downstream flange of each 66-inch outlet pipe. Both valves are operated from a common control cabinet located on a concrete platform above the valves as shown on Drawing No. 54 (591-D-922). Dial-type position indicators are provided in the control cabinet. Remote controls are not provided.

(1) Hollow-jet valve. --The hollow-jet valve is of welded and cast steel construction and consists basically of a body and a needle which is moved axially by oil pressure to control the flow of water. The needle is mounted on a plunger which is received and guided by an oil cylinder located on the longitudinal centerline of the valve. The cylinder is positioned in the body by six radial splitters as shown on Drawing No. 55 (591-D-923). The needle has a travel of of 23 inches and moves upstream to close the valve. As the valve is opened, water flows past the periphery of the needle in the shape of a cylindrical ring along the inside of the valve body. The splitters which support the needle, cut the ring into sectors and the water discharges from the valve in six separate jets.

(2) Control cabinet.--The control cabinet contains the control system for both hollow-jet valves as shown on Drawing No. 57 (591-D-1038). The equipment in the cabinet consists of two oil pumps, each having a capacity of approximately 10 gallons per minute, when pumping oil at 1,000 pounds per square inch; two 7-1/2-horsepower, 440-volt, 3-phase, 60-cycle electric motors; connecting piping; and hydraulic and electric controls. A 350-gallon oil supply tank is located on top of the cabinet. An oil level gage is located on the front of the supply tank.

c. Operating data.--

(1) Hollow-jet valve.--The hollow-jet valves are designed to regulate the discharge from the 66-inch outlet pipes under any head up to 430 feet. An oil pressure of 760 pounds per square inch is required in the closing chamber of the cylinder to balance a static head of 430 feet on the upstream face of the needle when the valve is closed. The valve is held in the closed position, or at any intermediate position by confining oil in the opening and closing chambers of the valve cylinder. The opening time is variable and the valve should be adjusted to open in about 5 minutes. A period of approximately 5 minutes is required to close each hollow-jet valve.

The hollow-jet valve was furnished by Acciaieria e Tubificio di Brescia, Via Zara, Italy, under Invitation No. DS-5416.

(2) Control cabinet.--One set of hydraulic control piping leads from the control cabinet to each hollow-jet valve. Hand valves are provided on each set of pipelines to direct the oil pressure to the hollow-jet valve which is to be operated. Only one hollow-jet valve should be operated at a time. For normal operation both pumps operate; however, if one pump or motor should become inoperable, a hollow-jet valve can be operated at half speed with one pump. For detailed operating data, refer to operating diagrams and instructions, Drawing No. 58 (591-D-1039).

Controls for the hollow-jet valve were furnished by Kendo, Incorporated, 5700 Fairfax Street, Denver, Colorado 80216 under Invitation No. DS-5641.

d. Maintenance.--A periodic program of inspection, maintenance, and painting should be established to keep all equipment in first-class operating condition.

(1) Inspect paint on hollow-jet valves and examine them for cavitation after any extended period of use.

(2) Scale forming on the plunger, seal or seat of the hollow-jet valve shall be removed before it becomes great enough to damage the packings.

(3) Gland leakage can be eliminated by shimming between the packing rings and the packing glands. If leakage is not stopped by a reasonable amount of shimming, the packing should be replaced. Overtightening of the packings because of too much shimming is likely to damage the plunger.

(4) An entire hollow-jet valve may be handled as shown on Drawing No. 55 (591-D-923). Weight of one complete valve is 45,000 pounds. Weight of major valve parts: Downstream body 21,500 pounds, upstream body 11,000 pounds, needle 5,000 pounds, plunger 3,300 pounds, cylinder head 2,000 pounds.

(5) Service and maintain the control system as shown on Drawing No. 58 (591-D-1039).

27. Operation

The river outlets shall be operated to their maximum allowable capacity of 4,000 cubic feet per second prior to use of the spillway gates. Discharge curves for the outlet works are shown on Drawing No. 59 (591-D-832).

a. Filling.--For details of filling lines see Drawing No. 49 (591-D-659).

(1) Upstream outlet pipe.--Steps for filling the outlet pipe upstream from the ring-follower gate are as follows:

(a) Open the upstream filling valve on the empty outlet pipe.

(b) Open the valve in the interconnecting line.

(c) Open the upstream filling valve on the full outlet pipe.

(d) When the outlet pipe is full, the bulkhead gate may be removed.

(e) Close the three filling line valves.

(2) Downstream outlet pipe.--Steps for filling the outlet pipe downstream from the ring-follower gate are as follows:

(a) Open the 2-inch air vent valve.

(b) Close the 66-inch hollow-jet valve.

(c) Open the downstream and upstream filling valves in that order. (For filling other outlet pipe, open the downstream, interconnecting and upstream filling valves in that order.)

(d) When the outlet pipe has filled, water will flow from the 2-inch air valve. Close the air vent valve.

(e) The 66-inch ring-follower gate, now under balanced head, may be opened.

b. Unwatering.--

(1) Upstream outlet pipe.--Steps for unwatering the upstream outlet pipe are as follows:

(a) The 66-inch ring-follower gate will be in the open position (normal operation).

(b) Close the 66-inch hollow-jet valve.

(c) Place the bulkhead gate in the closed position.

(d) Open the hollow-jet valve slightly, to slowly drain the outlet pipe. Air will enter the outlet pipe through the 10-inch check valve and line.

c. Maintenance.--The outlet pipes should be inspected periodically for leaks and to determine condition of coating and lining. A decision can then be made as to the necessity for maintenance work. Manhole covers must be carefully replaced after inspection and maintenance have been completed. Valves should be maintained in accordance with manufacturers' instructions.

United States Department of the Interior

TAKE PRIDE IN AMERICA

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Denver, Colorado 80225-0007

IN REPLY REFER TO:

D-5850

October 28, 1993

RO&M Examination Report

To: Chief, Operation and Maintenance Engineering Branch

From: W. P. Gersch and F. J. Francescatti

Subject: 1993 Review of Operation and Maintenance (RO&M) Examination Report - Flaming Gorge Dam, Powerplant, and Sidehill and Spillway Bridges (A) - Colorado River Storage Project, Utah-Wyoming - Upper Colorado Region

Flaming Gorge Dam and appurtenances were examined on August 17-19, 1993, as required under the RO&M Program, Part 231.2.3, of the Reclamation Instructions. Cooperation and assistance received from regional and field branch personnel are appreciated. Findings and recommendations were discussed at the dam following the examination.

REFERENCE DATA

Operating Organization

Bureau of Reclamation

Structure Completed

1964

Pertinent Drawings

591-D-142 - Flaming Gorge Dam and Power Plant - Plan, Elevation, and Sections
591-D-158 - Flaming Gorge Dam - Spillway - Plan and Sections
591-D-144 - Flaming Gorge Dam - Diversion Tunnel, Plan, Profile, and Sections
591-D-150 - Flaming Gorge Dam - River Outlets - Plan, Profile, and Sections

Designers' Operating Criteria

Flaming Gorge Dam, Powerplant, and Switchyard - Issued November 1963, revised December 1972
Flaming Gorge Community Facilities - issued July 1958

Standing Operating Procedures

Issued May 1979, revised August 1992, reissued May 26, 1993

Underwater/Dewatered Examinations

No basin. Underwater examination of powerplant outlet stilling basin and spillway gates in 1991. Very good condition. Spillway tunnel inspected during each RO&M exam.

Structural Performance Data

All data are current and performance is satisfactory.

Most current Structural Behavior Report: April 21, 1993
Most recent Schedule for Periodic Readings (L-23): July 1990

Landslide Potential

Slide area at powerplant left abutment last examined in 1992.

Previous Examinations

Periodic examinations have been made of these facilities since 1968 by regional and Denver Office personnel under the RO&M Program. The last examination was made in 1990 by regional office personnel. Copies of all RO&M reports are on file in the Denver Office, Operation and Maintenance Engineering Branch, code D-5850.

SYNOPSIS OF EXAMINATION

Dates of Examination

August 17-19, 1993

Examination Team

Steve Thompson, Operations Foreman, Flaming Gorge Dam
Ray Alt, Mechanical Foreman, Flaming Gorge Dam
Tom Ryan, Water Operations Branch, Upper Colorado Regional Office
Frank J. Francescatti, Mechanical Branch, Denver Office
W. P. Gersch, Operation and Maintenance Engineering Branch, Denver Office

Facilities Examined

Dam, spillway, sidehill and spillway bridges (A), outlet works, powerplant, and visitor's center

Operating Status at Time of Examination

Reservoir water surface elevation: 6033.04 feet
Reservoir storage: 3,465,560 acre-feet

Reservoir Allocation Data

Top of active conservation: 6040.0 feet
Total capacity: 3,788,700 acre-feet

Releases
Spillway: None
Outlet works: None
Powerplant: 909 ft^3/s through Unit No. 2

Safe Downstream Channel Capacity

Combined spillway, outlet works, and powerplant: 5,000 ft^3/s

Operational History

Maximum reservoir elevation to date: 6043.79 feet on July 19, 1983

During the flooding in July 1983, the maximum discharge from the dam was 13,000 ft^3/s for 6 hours.

Spillway: 5,000 ft^3/s in July 1983 for 6 hours

Outlet works: 4,000 ft^3/s in July 1983 for 6 hours

Powerplant: 4,000 ft^3/s in July 1983 for 6 hours

Recommendations

Status of Previous Recommendations

Category 1

92-1-A Prepare and distribute an Emergency Preparedness Plan (EPP) conforming to latest guidelines (per 4-28-92 memo from region).

Completed.

Category 2

87-2-0 Finalize the Standing Operating Procedures (SOP) to conform to the latest guidelines. Include instructions on gate exercising and operation of the selective withdrawal structure (Denver).

Completed.

87-2-P Prepare an Emergency Preparedness Plan including preparation and distribution of an inundation map (Denver).

Completed.

89-2-A Bridge - Develop and implement a plan for regular inspections and periodic removal of loose rocks from cliffs above the sidehill bridge (Region).

Completed.

90-2-A Clean, sandblast, and repaint the three unit bell drain valves (Region).

Completed.

90-2-B Clean, sandblast, and paint the metal bracing remaining on the spillway gates from the removed flashboards (Region).

Completed.

90-2-C Install two life preserver throwable rings on crest of dam (Region).

Completed.

Category 3

91-3-A Bridge - Place caulking compound between concrete and guard post for watertight protection on sidehill bridge (Region).

Completed.

New Recommendations

Category 2

93-2-A Clean and repair corrosion damage in outlet pipes No. 1 and 2.

93-2-B Repair fence to left of outlet works discharge valve structure.

Category 3

None.

EXAMINATION

Dam

Flaming Gorge Dam is a concrete variable thickness thin arch structure constructed between 1956 and 1964. It has a structural height of 502 feet and a hydraulic height of 448 feet. The crest length (arc length at axis of dam) is 1,285 feet and the theoretical crest thickness is 20 feet; however, a cantilevered section at the top of the dam increases the top width to 34.25 feet to accommodate a two-lane 27-foot-wide roadway, sidewalks, and parapets. The elevation of the crest is 6047 feet and the maximum base thickness is 131 feet. The roadways on the crest and the sidehill bridge are a part of the local transportation network and provide access across the gorge. Intakes for the river outlet works and the powerplant penstocks are mounted on the upstream face of the dam. The powerplant is located near the downstream toe of the dam. Access to the galleries at several elevations is at each abutment.

Due to the high water surface, only a small portion of the upstream face of the dam could be examined. The upstream face was examined by boat. The concrete of the visible portion of the upstream face (photographs 1 and 2) is in excellent condition with no indication of deterioration, cracking, or spalling. The concrete of the crest of the dam (photograph 3) is in good condition with no indication of cracking or spalling. The concrete of the elevator tower (photograph 4) is also in good condition. Two life preserver rings have been placed in the penstock gate control house and one life preserver ring has been placed in the visitor's center (90-2-C).

The concrete of the downstream face of the dam (photograph 5) is in good condition with no visible deterioration. The right (photograph 6) and left (photograph 7) abutment contact areas are clean and in good condition. There was no seepage at the right abutment contact and only minor seepage at the left abutment contact. However, there was seepage through the left downstream abutment (photograph 8). The seepage is being measured by two V-notch weirs (photograph 9) and is reported to remain constant. No measurement was taken during the examination.

The slide area on the left abutment above the powerplant was examined in September 1992 by the regional geologist. No change was observed.

The concrete in the utility gallery at elevation 6015.0 feet (photographs 10 and 11) is in good condition with no indication of seepage. The only moisture in the gallery was from condensation. There are two bubbler systems to prevent ice buildup: one in front of the outlet works trashracks and one in front of the spillway gates. Two compressors for each bubbler system are located at the left side of the utility gallery. One of each of the compressors (photographs 12 and 13) was started and operated satisfactorily. Each compressor is test operated weekly.

The concrete of the filling line gallery at elevation 5865.0 feet (photograph 14) is in good condition with no cracking or spalling observed. The three penstock bell drain valves (photograph 15) have been cleaned and painted

(90-2-A). The concrete of the access gallery at elevation 5737.5 feet (photograph 16) is in excellent condition and there was very little moisture present. The sump pumps for the gallery and abutment drainage (photograph 17) are in excellent condition. The sump pumps were operated satisfactorily. The concrete of the foundation gallery at elevation 5580.0 feet (photograph 18) is in excellent condition.

The elevator in the dam provides service for operation and maintenance personnel and the public. The elevator was used numerous times to access the galleries and performed satisfactorily. The elevator is inspected annually by the State of Utah. The elevator shaft metalwork (photograph 19) was in excellent condition.

Instrumentation at the dam consists of plumbline measurements, trilateration readings, uplift pressure measurements, drainage and seepage measurements, and resistance thermometers. Most of the instrumentation has been automated with readings transmitted directly to the Denver Office for analysis. Seepage measuring weirs (photograph 20) are located in the filling gallery. Photograph 21 shows a typical plumbline measuring unit and photograph 22 shows uplift pressure gauges located in the foundation gallery. All instrumentation readings are current and the dam is performing satisfactorily. The most recent Structural Behavior Report is dated April 21, 1993, and the most recent Schedule for Periodic Readings (L-23) was issued in July 1990.

Spillway

A concrete-lined tunnel spillway with a crest elevation of 6006 feet and net crest width of 33.5 feet is located in the left abutment of the dam. The tunnel varies in diameter from 26.5 feet at the upstream portal to 18 feet at the downstream portal and is 675 feet long. Discharges are controlled by two 16.75- by 34-foot fixed-wheel gates which are capable of passing 28,800 ft^3/s at maximum water surface elevation 6045 feet.

The concrete of the spillway crest and gate structure (photograph 23) is in good condition with only some minor spalling at the left crest structure wall. The concrete of the tunnel throat section (photograph 24) is in good condition with no cracking or spalling observed. The concrete of the spillway tunnel (photograph 25) is in excellent condition with no spalling or cracking observed. The spillway, outlet works, and powerplant stilling basin and discharge channel (photograph 26) are clean and in good condition. The stilling basin was examined by divers in October 1991 and was found in very good condition.

The upstream faces of the spillway fixed-wheel gates were examined by boat. The visible portions of the gates (photograph 27) are in good condition. Trash barriers (photograph 28) have been added to the tops of both gates. The barriers are mounted to the gates so that water will pass between the barriers and the gates and so that trash is prevented from being washed over the gates into the spillway tunnel. All metalwork on top of the gates has been cleaned and painted (90-2-B). The downstream faces of the fixed-wheel gates (photograph 29) are in good condition and the gates are sealing satisfactorily with only a minor amount of seepage. The wire ropes and connectors (photograph 30) are in excellent condition. The wire ropes on the hoists are on a 3-year maintenance schedule and are in good condition. The gate hoist structure (photograph 31) is well painted and in good condition. Maintenance is performed on the hoist annually, which includes checking for water in the oil tanks before the first freeze.

None of the gates were operated during this examination. The gates were last operated on July 26, 1993, according to the logbook. Each gate was opened 6 inches and then closed. Both gates operated satisfactorily.

Sidehill and Spillway Bridges (A)

The sidehill and spillway bridges are class A structures on a Federal-aid highway. See attached bridge inspection report for details of examination.

The spillway bridge is located to the left of the dam. The concrete of the top of the spillway bridge (photograph 32) is in good condition with no cracking or deterioration. The metal beams on the bottom of the bridge (photograph 33) have good protective coatings and are in good condition.

The sidehill bridge (photograph 34) is adjacent to the spillway bridge. The concrete in the top of the bridge (photograph 35) is generally in good condition. Caulking has been placed between the concrete and the guard posts to provide a watertight seal (91-3-A). In the spring of 1993, the cliff above the bridge was cleaned of all loose rock (89-2-A). During the cleaning operation, a large rock fell and put a hole through the bridge deck. A section of the bridge deck was cut out and repairs were made (photographs 36 and 37). The concrete beams and support columns at the bottom of the bridge (photograph 38) are in good condition with no spalling or cracking. The bearing devices at the bottom of the bridge (photograph 39) are in good condition.

Outlet Works

The outlet works through the dam consists of two 72-inch steel pipes which reduce to 66 inches at the two ring-follower gates and continue downstream to the two 66-inch hollow-jet valves. The discharge is directed into the river channel downstream from the powerplant tailrace. The maximum discharge of the two outlets is 4,000 ft^3/s at maximum water surface elevation 6045 feet.

The outlet works intake structure and upstream pipe were submerged and could not be examined. The intake structure was examined by divers in 1990 and was found to be in very good condition. The bulkhead gate used to seal the intakes for the outlet works is kept in the storage yard in Dutch John. The bulkhead gate and its lifting frame (photographs 40, 41, and 42) were found to be in good condition.

At the time of the examination, both 66-inch ring-follower gates were closed and the two hollow-jet valves were each open 12 percent. The 12-percent opening is required to provide the desired 400 ft^3/s discharge downstream in the event of an unscheduled shutdown of the powerplant, which automatically opens one of the ring-follower gates. For this reason, the outlet pipes were opened for inspection one at a time, leaving the remaining pipe operational. We examined outlet pipe No. 2 and then outlet pipe No. 1. Each outlet pipe was examined by entering through a manhole (photograph 43) provided just downstream of the ring-follower gate. The downstream face of each ring-follower gate (photographs 44 and 45) is in good condition with only minor leakage (photographs 46 and 47). Leakage reported previously has not changed since the last examination. The damage due to corrosion in the invert of both discharge pipes immediately downstream of the ring-follower gates (photographs 48 and 49), which was previously reported, has worsened. The pitting due to corrosion has increased to the point that repairs are necessary. It is recommended that the corrosion damage in the No. 1 and No. 2 outlet pipes be cleaned and repaired (93-2-A). The remaining protective linings of the outlet pipes, down to the hollow-jet valves, are in excellent condition. The coatings on the exteriors of the exposed portions of the outlet pipes are in good condition.

The 66-inch hollow-jet valve needles (photographs 50 and 51) are in good condition. The remaining areas of the hollow-jet valves (photograph 52) are also in good condition. The protective coatings on the valves show areas of spot repair and painting. The control cabinet for the valves, located on the deck directly above the hollow-jet valves, is in good condition and operating instructions are posted (photograph 53). A section of the fence next to the hollow-jet valve structure is missing (photograph 54) and needs to be repaired (93-2-B).

The hydraulic cylinders and bypass piping for the 66-inch ring-follower gates (photograph 55) and all the other metalwork are well painted and in excellent condition. The control cabinet for the ring-follower gates (photograph 56) was clean with no indication of oil leakage, and operating instructions are posted.

None of the gates and valves were operated during the examination. Records in the logbook indicate that the river outlets were watered up on February 24, 1993. At that time, both ring-follower gates were fully opened and the hollow-jet valves were each opened 10 percent. The ring-follower gates were then closed. All gates and valves reportedly operated satisfactorily.

A standby engine-generator used as emergency backup power to operate the ring-follower gates, hollow-jet valves, and fixed-wheel spillway gates is located behind the powerplant (photograph 57). The engine-generator was started and operated satisfactorily. The engine-generator is started weekly and operates for about 10 minutes. None of the mechanical equipment was operated with the engine-generator because the generator is not permanently hooked up. In order to use the engine-generator, the entire plant would have to be shut down to acquire what is referred to as a dead bus, which is needed to come on line with the emergency power.

Powerplant

The powerplant, located at the downstream toe of the dam, contains three turbines and generators. The capacity of each unit is 36,000 kilowatts. Three 10-foot-diameter steel-lined penstocks are located in the central part of the dam; each serves one of the 50,000-horsepower turbines.

Examination of the powerplant consisted of the structural features only. The electrical and mechanical equipment are examined by power O&M personnel in the Operation and Maintenance Engineering Branch, Denver Office.

The concrete in the exterior of the powerplant structure and the forebay (photograph 58) is in good condition with no indication of spalling or cracking. The roof of the powerplant (photograph 59) is in satisfactory condition and there is no report of leakage. The concrete at the lower level of the powerplant (photograph 60) is in good condition with no cracking or seepage observed. The concrete on the second level of the powerplant (photograph 61) is in excellent condition with no cracking or spalling. All structural features on the upper level of the powerplant (photograph 62) are in good condition. The powerplant crane (photograph 63) has a good protective coating and is in good operating condition.

The selective withdrawal structures for the powerplant penstocks were examined from the reservoir by boat. All the painted and galvanized portions of the structure are in excellent condition. Trashracks were added to the structure in 1990. The protective coatings on the exposed portions of the trashracks (photographs 64 and 65) are in excellent condition. The shutters which are suspended from wire ropes and are raised and lowered by hoists mounted on the operating deck above each penstock trashrack structure were reported to operate satisfactorily. They are accomplishing their designed purpose of selecting the water elevation which has the most desirable water temperature. At the time of the examination, the water temperature indicated in the control cabinet (photograph 66) was 54 degrees. The selective withdrawal structures were last examined by underwater camera in 1990, and were found to be in good condition. All metalwork on the hoist deck (photograph 67) is well maintained and in very good condition. The visible portions of the wire ropes were examined and found to be in good condition with no signs of fraying or wear.

Visitor's Center

The visitor's center is located to the right of the dam. The exterior of the visitor's center (photographs 68 and 69) is in excellent condition with no visible damage to any of the facing. The roof of the visitor's center (photograph 70) is in excellent condition. The gravel is spread very evenly and there is no indication of soft spots or bubbling. The structural features on the interior of the visitor's center are also in good condition.

Factors Affecting Operations

Flaming Gorge Dam is operated and maintained by the Bureau of Reclamation. Access to the site is by paved all-weather U. S. Highway No. 191 and is adequate. Communications at the dam consist of a public telephone, a microwave telephone system, and a VHF radio system with fixed and mobile units. Communications are considered adequate. Security at the dam is maintained by locked doors on the office and powerhouse, and a locked gate to the entrance of the powerplant, and is considered adequate. The dam is attended during normal working hours 5 days a week. Operation and maintenance personnel live in Dutch John, Utah, approximately 3 miles from the dam and are available in an emergency. This is considered adequate.

A revised SOP was issued on May 26, 1993. It conforms to the latest guidelines and includes instructions on gate exercising and operation of the selective withdrawal structures (87-2-O). The SOP contains an EPP (92-1-A) including an inundation map and a list of equipment available in an emergency (87-2-P). No meeting has been held with local authorities in recent years regarding the EPP nor has there been an emergency exercise conducted. The EPP is reviewed annually. There is no designated flood control space in the reservoir. The reservoir elevation and releases are monitored 24 hours a day from the Glen Canyon Control Center and releases are made as required.

A Hazardous Materials Management Program has been established, but no formal review has been performed. There is no Integrated Pest Management Program in place. Pesticide use proposals are developed for each application when required.

A logbook is being maintained in the powerplant operations office. The logbook contains all pertinent information regarding the operation and maintenance performed at the dam. The logbook was signed by the examination team.

All operations personnel have received classroom and on-site dam tender's training. The last refresher course was received on April 29, 1989. The regional office should schedule a dam tender's training session for all operation and maintenance personnel to conform with the required 3-year schedule.

The dam is operated and maintained using the Project Operations Maintenance Management System.

A Safety Evaluation of Existing Dams Analysis Summary was issued on April 28, 1992. The analysis concluded that the overall Safety of Dams classification for Flaming Gorge Dam is fair. No Modification Decision Analysis has been prepared for this dam; it is scheduled for completion in fiscal year 1994.

Special studies are currently in progress to provide for adequate releases to protect endangered species (fish). A minimum release of 400 ft^3/s is currently required.

Conclusions

Based upon the condition of Flaming Gorge Dam and appurtenances at the time of the examination, operation and maintenance are being performed in an excellent manner. Operation and maintenance personnel are commended for their efforts. There are no incomplete recommendations and two new category 2 recommendations are made as a result of this examination.

W. P. Gersch 10/28/93

W. P. Gersch, D-5850 — Date
Field Examiner

F. J. Francescatti 10-28-93

F. J. Francescatti, D-3422 — Date
Field Examiner

Approved: David O. Allen 11/1/93

David O. Allen, Chief — Date
Operation and Maintenance
Engineering Branch

Attachment

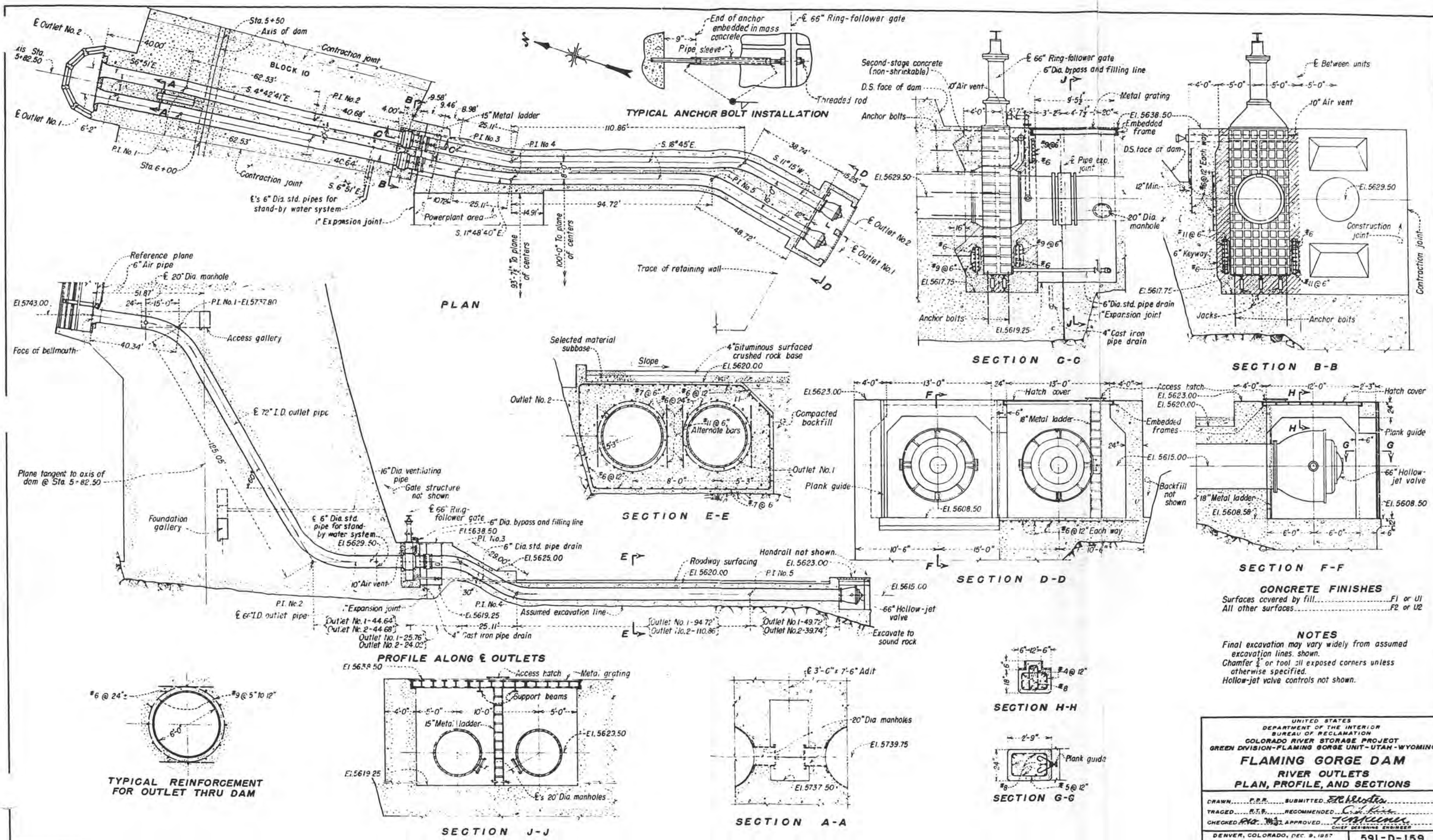
Copy to: Assistant Commissioner - Program, Budget, and Liaison, Attention: W-6500 (1)
Regional Director, Salt Lake City, Utah, Attention: UC-400 (14)

Blind to: D-5850
D-3111
D-3420

WPGersch\FJFrancescatti:WP51\ROM\REPORTS\FLAMGORG.R93

Appendix D

Reference Drawings



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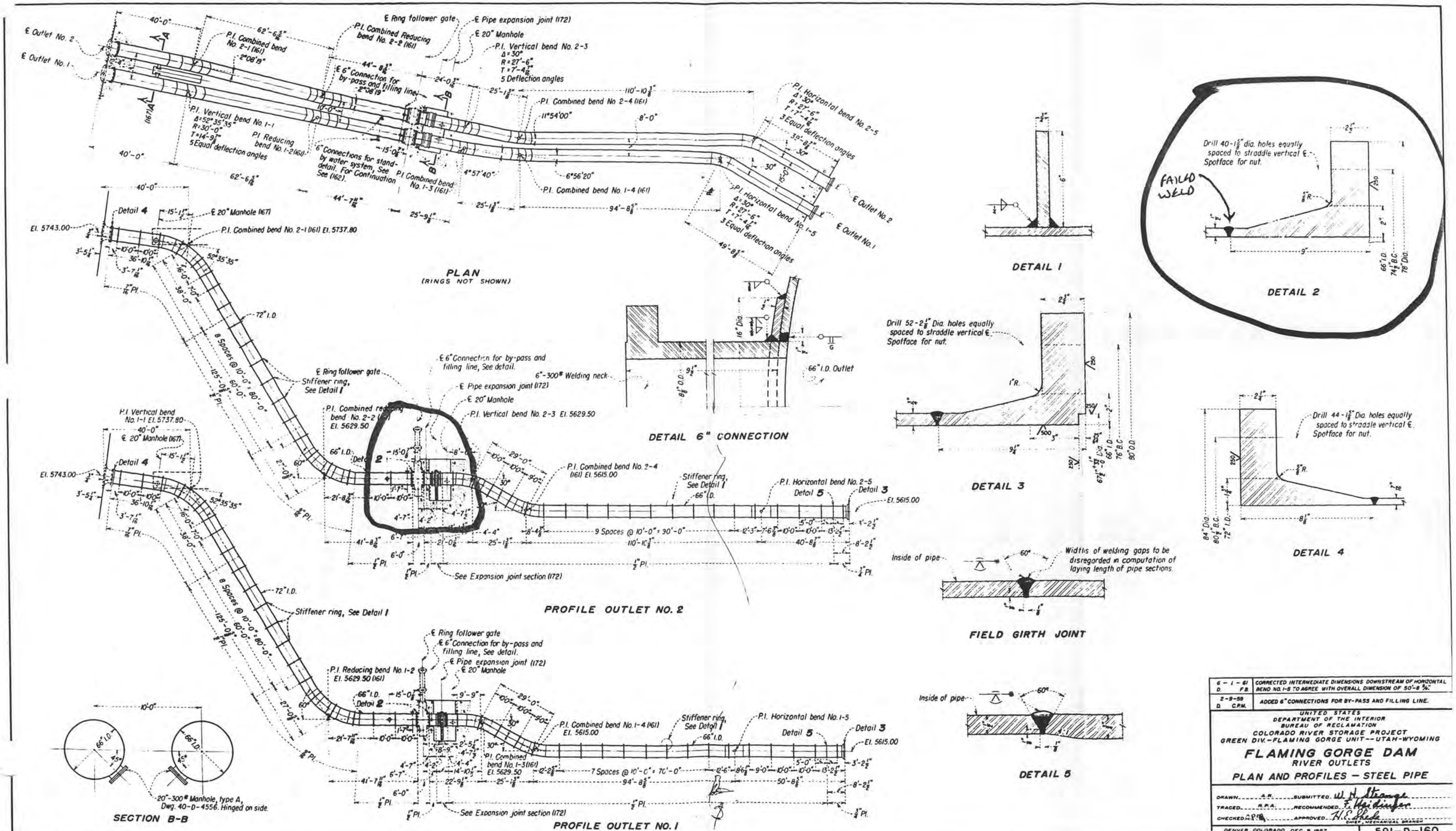
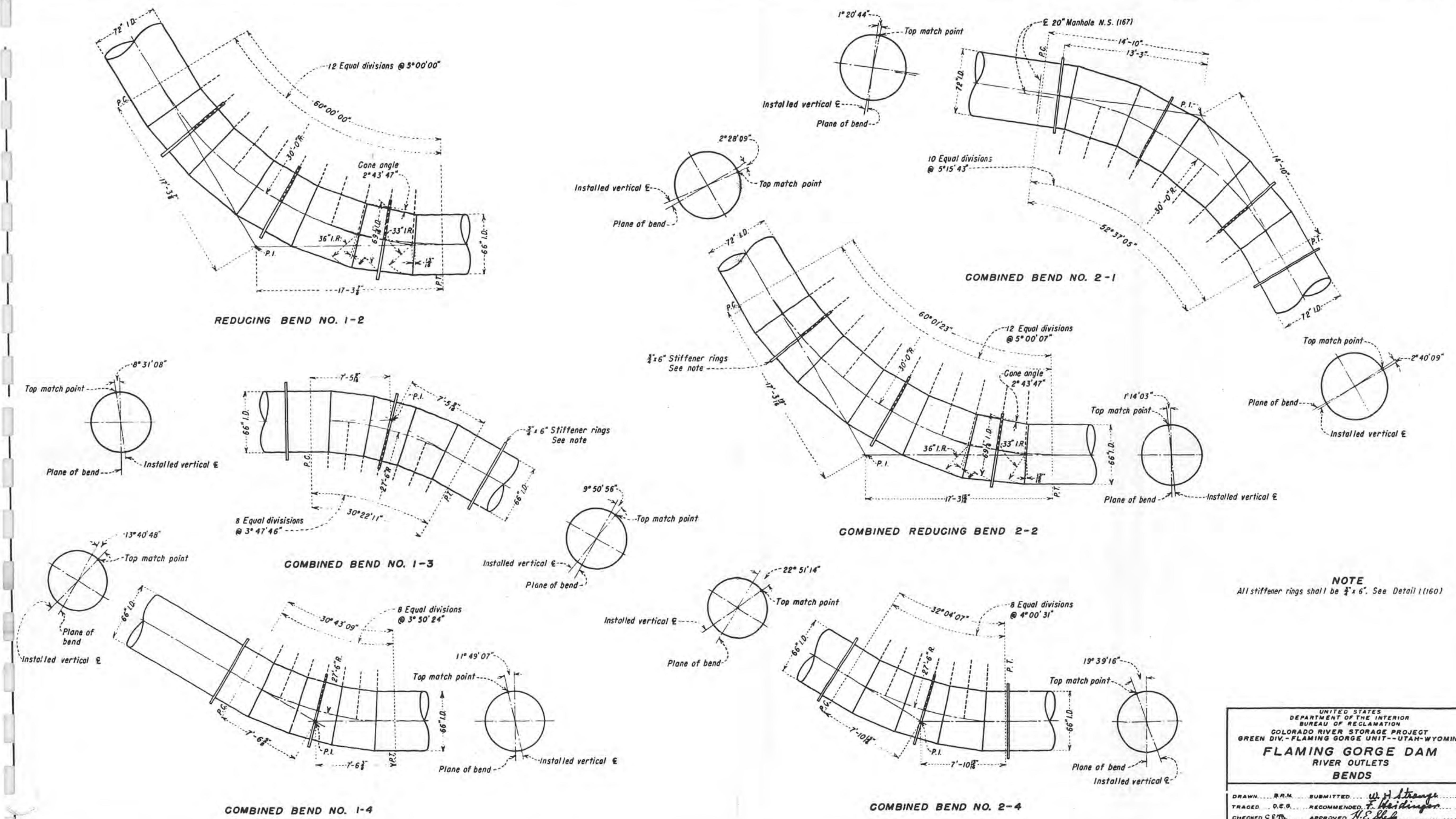


PLAN
(RINGS NOT SHOWN)
℄ Outlet No. 2
℄ Outlet No. 1
℄ Ring follower gate
℄ Pipe expansion joint (172)
℄ 20" Manhole
P.I. Combined bend No. 2-1 (161)
P.I. Combined Reducing bend No. 2-2 (161)
P.I. Vertical bend No. 2-3
Δ=30° R=27'-6" T=7'-4$\frac{3}{8}$" 5 Deflection angles
P.I. Combined bend No 2-4 (161)
P.I. Horizontal bend No. 2-5
Δ=30° R=27'-6" T=7'-4$\frac{3}{8}$" 3 Equal deflection angles
P.I. Vertical bend No. 1-1
Δ=52°35'35" R=30'-0" T=14'-9$\frac{7}{8}$" 5 Equal deflection angles
P.I. Reducing bend No. 1-2 (161)
6" Connections for stand-by water system, See detail. For Continuation See (162).
℄ 6" Connection for by-pass and filling line
P.I. Combined bend No. 1-3 (161)
P.I. Combined bend No. 1-4 (161)
P.I. Horizontal bend No. 1-5
Δ=30° R=27'-6" T=7'-4$\frac{3}{8}$" 3 Equal deflection angles
℄ Outlet No. 2
℄ Outlet No. 1
PROFILE OUTLET NO. 2
Detail 4
℄ 20" Manhole (167)
P.I. Combined bend No. 2-1 (161) El. 5737.80
El. 5743.00
72" I.D.
8 Spaces @ 10'-0" = 80'-0"
Stiffener ring, See Detail 1
P.I. Combined reducing bend No. 2-2 (161) El. 5629.50
℄ 6" Connection for by-pass and filling line, See detail.
6"-300# Welding neck
℄ Pipe expansion joint (172)
℄ 20" Manhole
P.I. Vertical bend No. 2-3 El. 5629.50
66" I.D.
Detail 2
P.I. Combined bend No. 2-4 (161) El. 5615.00
Stiffener ring, See Detail 1
P.I. Horizontal bend No. 2-5
Detail 5
Detail 3
El. 5615.00
9 Spaces @ 10'-0" = 90'-0"
See Expansion joint section (172)
PROFILE OUTLET NO. 1
P.I. Vertical bend No. 1-1 El. 5737.80
℄ 20" Manhole (167)
Detail 4
El. 5743.00
72" I.D.
8 Spaces @ 10'-0" = 80'-0"
Stiffener ring, See Detail 1
℄ Ring follower gate
℄ 6" Connection for by-pass and filling line, See detail.
℄ Pipe expansion joint (172)
℄ 20" Manhole
P.I. Reducing bend No. 1-2 El. 5629.50 (161)
66" I.D.
Detail 2
P.I. Combined bend No. 1-3 (161) El. 5629.50
P.I. Combined bend No. 1-4 (161) El. 5615.00
Stiffener ring, See Detail 1
P.I. Horizontal bend No. 1-5
Detail 5
Detail 3
El. 5615.00
7 Spaces @ 10'-0" = 70'-0"
See Expansion joint section (172)
SECTION B-B
20"-300# Manhole, type A, Dwg. 40-D-4556. Hinged on side.
DETAIL 6" CONNECTION
16" Dia.
66" I.D. Outlet
DETAIL 1
DETAIL 2
Drill 40-1$\frac{5}{8}$" dia. holes equally spaced to straddle vertical ℄. Spotface for nut.
FAILED WELD
DETAIL 3
Drill 52-2$\frac{1}{8}$" Dia. holes equally spaced to straddle vertical ℄. Spotface for nut.
DETAIL 4
Drill 44-1$\frac{5}{8}$" Dia. holes equally spaced to straddle vertical ℄. Spotface for nut.
FIELD GIRTH JOINT
Inside of pipe
Widths of welding gaps to be disregarded in computation of laying length of pipe sections.
DETAIL 5
Inside of pipe
6-1-61 D. F.B. CORRECTED INTERMEDIATE DIMENSIONS DOWNSTREAM OF HORIZONTAL BEND NO. 1-5 TO AGREE WITH OVERALL DIMENSION OF 50'-8 $\frac{5}{8}$".
2-9-59 D. C.P.M. ADDED 6" CONNECTIONS FOR BY-PASS AND FILLING LINE.
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER STORAGE PROJECT
GREEN DIV.-FLAMING GORGE UNIT--UTAH-WYOMING
FLAMING GORGE DAM
RIVER OUTLETS
PLAN AND PROFILES – STEEL PIPE
DRAWN A.E. SUBMITTED W. H. Strange
TRACED R.R.A. RECOMMENDED F. Heidinger
CHECKED APPROVED H. E. Steele CHIEF, MECHANICAL BRANCH
DENVER, COLORADO, DEC. 9, 1957
591-D-160



UNITED STATES
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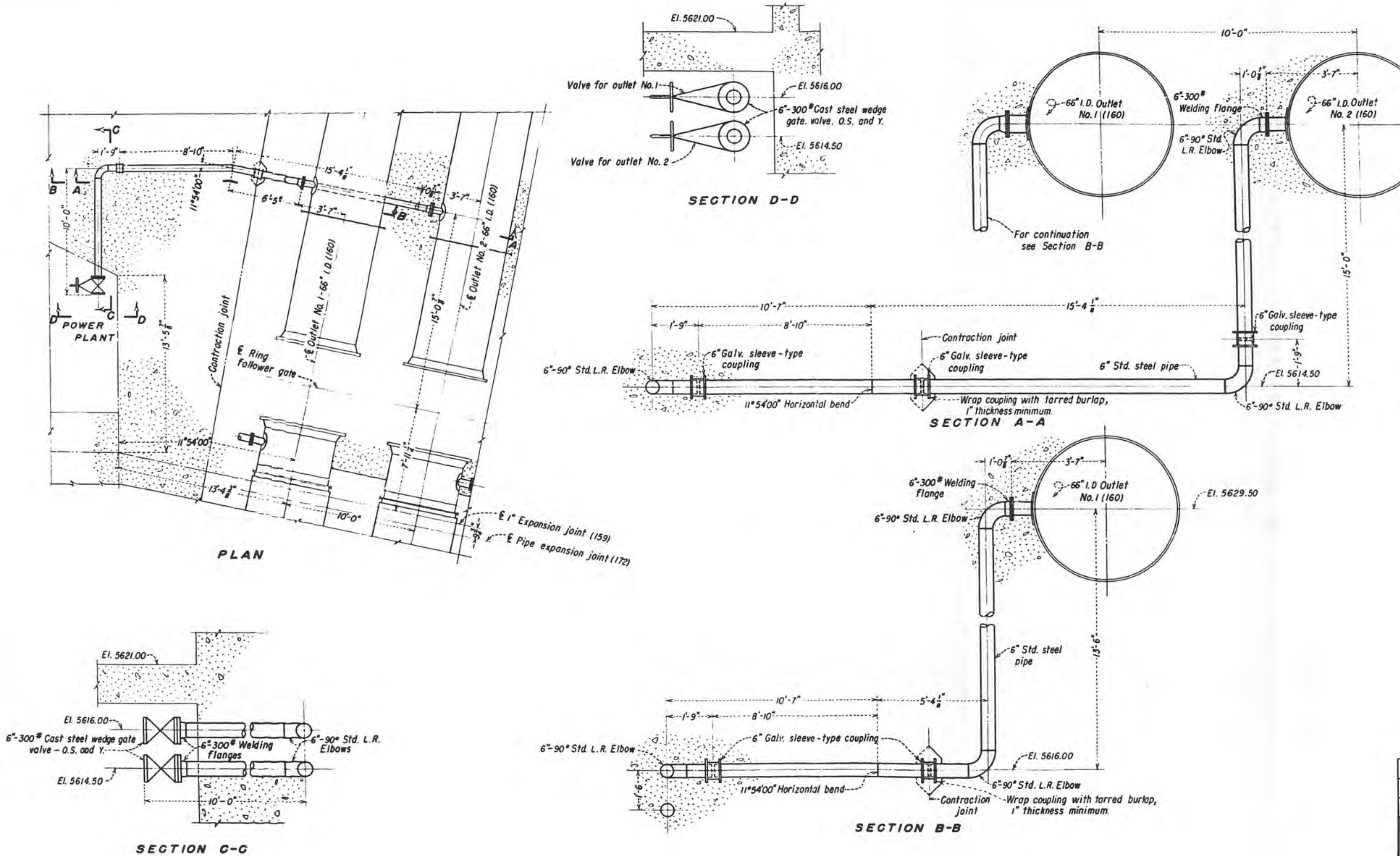
COLORADO RIVER STORAGE PROJECT
GREEN DIV.-FLAMING GORGE UNIT--UTAH-WYOMING

FLAMING GORGE DAM
RIVER OUTLETS
BENDS

DRAWN B.R.M. SUBMITTED W. H. Strange
TRACED D.E.G. RECOMMENDED F. Heidinger
CHECKED C.E.M. APPROVED H. E. Slade CHIEF MECHANICAL BRANCH
DENVER, COLORADO, DEC. 9, 1957 591-D-161

21436



GENERAL NOTE

All flanges to be 300# welding neck flanges complete with bolts, nuts and gaskets.
All piping to be galvanized.

3-29-60 D. F.B.	CHANGED DIMENSIONS IN PLAN VIEW FROM 7'-11 11/16" TO 7'-11 1/4" AND FROM 9 5/16" TO 9 3/4" TO AGREE WITH DWG. 591-D-519
9-11-58 D. F.B.	CHANGED ELEVATIONS AND DISTANCE FROM OUTLET PIPE DUE TO CONCRETE LIFT INTERFERENCE.
5-6-58 D. F.B.	CHANGED DIMENSIONS IN SECTION A-A, B-B AND PLAN VIEW.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER STORAGE PROJECT
GREEN DIVISION-FLAMING GORGE UNIT-UTAH-WYOMING

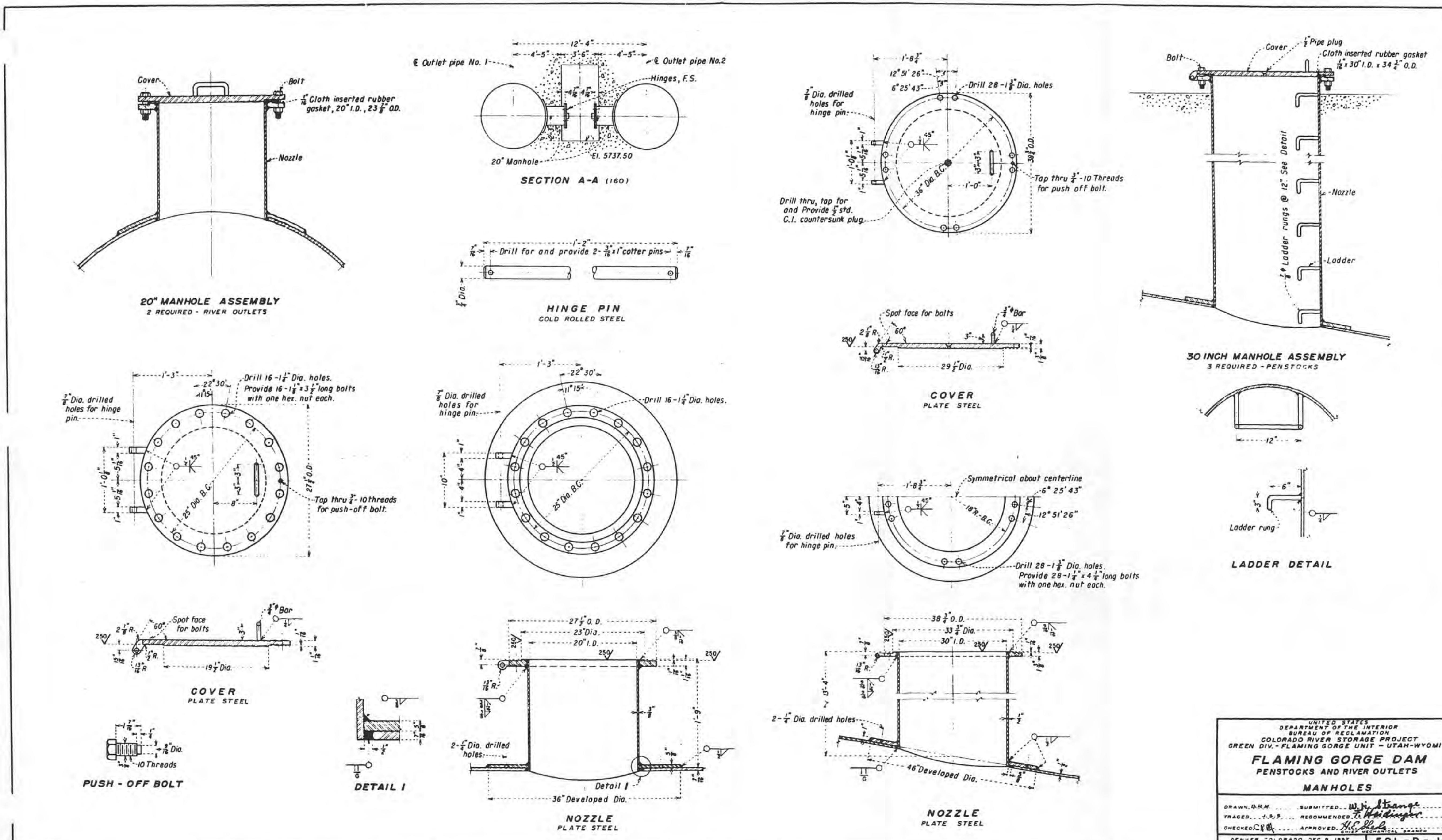
FLAMING GORGE DAM

CONNECTIONS FOR STAND-BY WATER SUPPLY PLAN AND SECTIONS

DRAWN M.L.R. SUBMITTED W. H. Strange
TRACED F.J.F. RECOMMENDED F. Haidinger
CHECKED C.V.D. APPROVED H. E. Sheda, CHIEF MECHANICAL BRANCH

DENVER, COLORADO, DEC. 9, 1957 | 591-D-162

JOB # 4-6891-11-01-01



UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER STORAGE PROJECT
GREEN DIV. - FLAMING GORGE UNIT - UTAH-WYOMING

FLAMING GORGE DAM

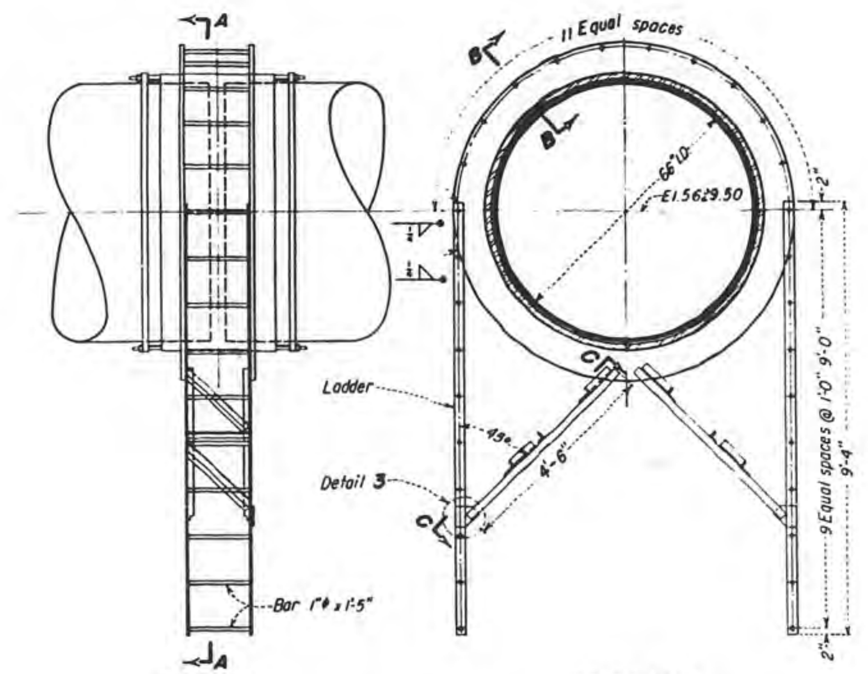
PENSTOCKS AND RIVER OUTLETS

MANHOLES

DRAWN D.R.M. SUBMITTED W. H. Strange
TRACED J.S.S. RECOMMENDED T. Weidinger
CHECKED C.W.M. APPROVED H. E. Hale, CHIEF MECHANICAL BRANCH
DENVER, COLORADO, DEC. 9, 1957

591-D-167

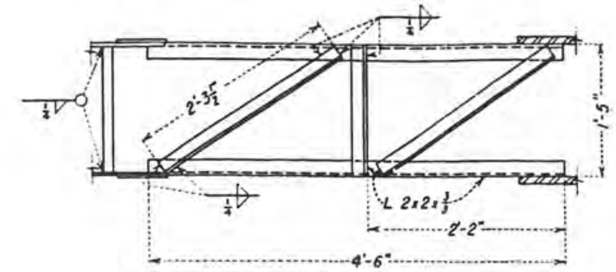
Job No. 4-G591-11-01
(2/13)



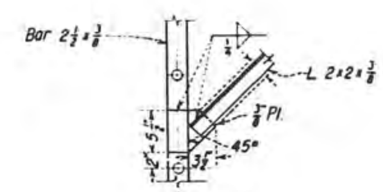
ELEVATION

SECTION A-A

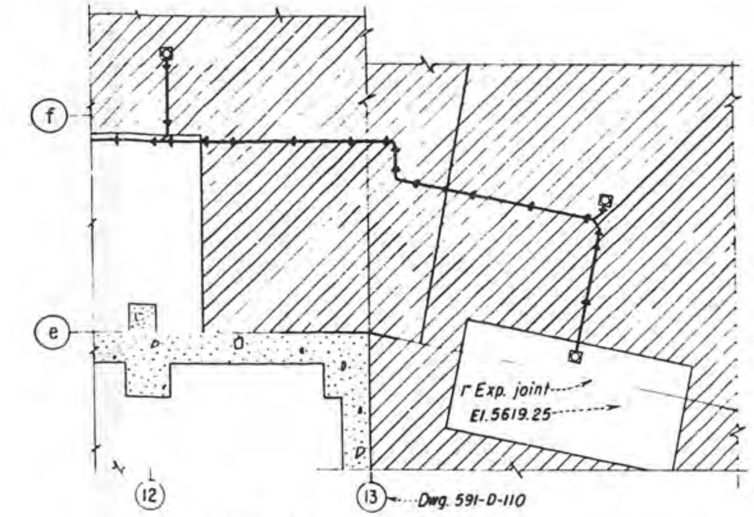
EXPANSION JOINT



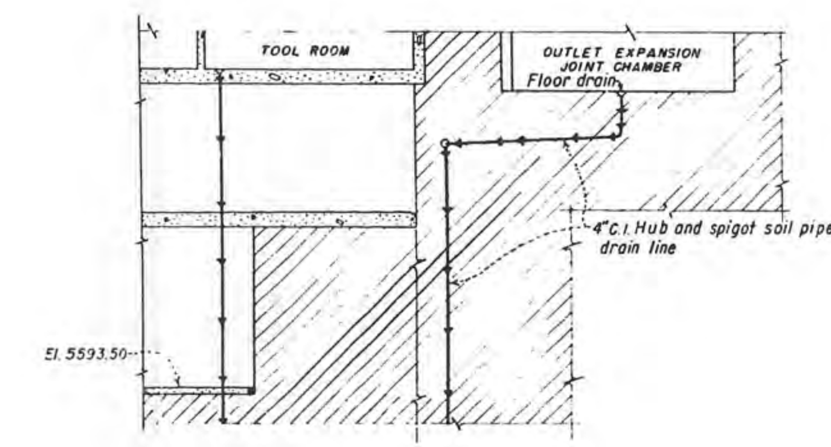
VIEW C-C



DETAIL 3

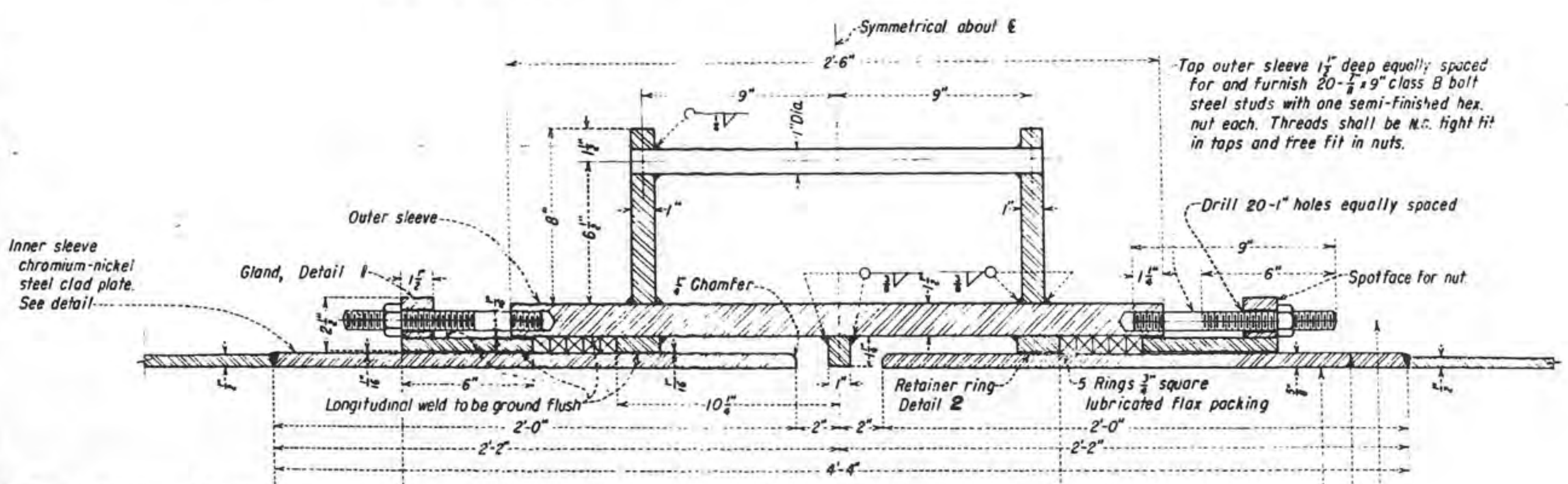


PLAN

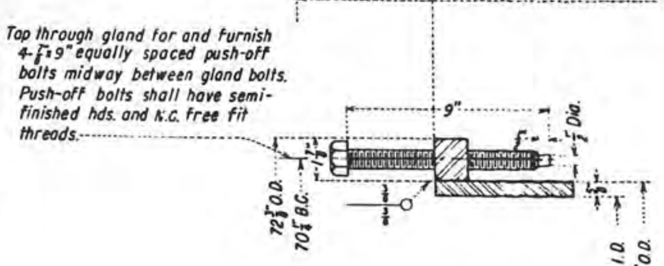


PROFILE
DRAIN LINE

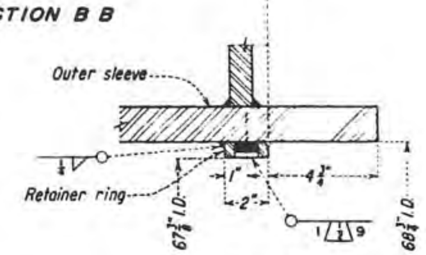
Details of drain piping are shown on Dwg. 591-D-225.



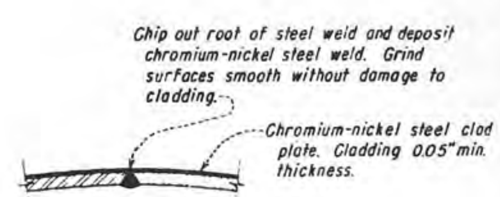
SECTION B B



DETAIL 1



DETAIL 2



LONGITUDINAL WELD
IN INNER SLEEVE

4-25-59 D. F.B.	REVISED DRAIN LINE PLAN AND PROFILE TO AGREE WITH DETAILED DRAWING.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER STORAGE PROJECT
GREEN DIV.–FLAMING GORGE UNIT – UTAH-WYOMING

FLAMING GORGE DAM
RIVER OUTLETS

EXPANSION JOINT AND DRAIN LINE

DRAWN W.P.T. SUBMITTED W.H. Stranger
TRACED R.L.D. RECOMMENDED F. Heidinger
CHECKED C.L.R. APPROVED H.C. Slade CHIEF, MECHANICAL BRANCH
DENVER, COLORADO, DEC. 9, 1957 591-D-172

(21X36) 4-G591-11-01-01

FLAMING GORGE RIVER OUTLET PIPE FAILURE
ROOT CAUSE ANALYSIS

FLAMING GORGE DAM
FLAMING GORGE FIELD DIVISION
COLORADO RIVER STORAGE PROJECT
UPPER COLORADO REGION

Roger Cline

Roger Cline, Mechanical Engineer

William D. McStraw

William D. McStraw, Mechanical Engineer

Gary D. Osburn

Gary D. Osburn, Electrical Engineer

Bert Milano

Peer Review/Concurrence
Bert Milano, Manager
Hydroelectric Research and
Technical Services Group