RESONANCE AT NAVAJO DAM OUTLET WORKS
AUGUST 27, 1979

HENRY T. FALVEY, TECHNICAL SPECIALIST

OPTIONAL FORM NO. 10
JULY 1973 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

Memorandum

TO : Files

Denver, Colorado
DATE: August 27, 1979

FROM : Henry T. Falvey, Technical Specialist

SUBJECT: Resonance at Navajo Dam Outlet Works

INTRODUCTION

On May 23, 1979, unusual thumping noises of unknown origin were heard at Navajo Dam. This was the first time that the noises had been reported since the dam's dedication in September 1963. According to the engineers (7 to 10 individuals) and dam tender, the pulsations were so severe that they could easily be felt when standing on the dam crest of the access well. It was also reported that the noise was similar to that made by an air compressor when the pressure in the air receiver needs adjustment. Observers standing near the air vent to the 72-inch penstock located beneath the crest of the dam reported a gurgling sound from the vent (see attached travel report, June 29, 1979).

When the noises were heard, the reservoir was at elevation 1846.2 m and the two 1830-mm hollow-jet valves were each open 73 percent. The 760-mm outlet line was closed. The total discharge through the outlet works was about 106 m^3/s. The weather was reported calm. The noise was reported to occur for 5 to 15 seconds, stop for a short period, and then reoccur. Although no one went to the reservoir to make observations, no unusual vortex action was reported in the vicinity (this area is not restricted to boating). When the hollow-jet valves were each closed to a 54 percent opening, the noises ceased and did not resume.

Subsequent tests throughout the entire range of valve openings were unsuccessful in reestablishing the noise. The tests were conducted with a reservoir elevation of 1849.3. During the testing, high winds were present on the lake. These winds came out of the south and southwest.

The regularity of the noise and its characteristic of building up and dying away are indicative of the resonance within the outlet works. With resonance, or vibration, an exciter somewhere in the system acts as a forcing function whose period matches one of the critical periods in the outlet. When a periodic forcing function is introduced into a system, the phenomena of beats occurs before the steady-state oscillatory flow is established. Beats occur at frequencies that are the difference between the forcing frequency and the resonant frequency of the outlet. If the two frequencies are of about the same magnitude, the beat frequency will be very low. They are observed as slow variations in the amplitude of the oscillations.

Two methods are available to investigate the resonant characteristics of the outlet works. These are the frequency response or impedance method and the free vibration method. In the frequency response method, the behavior of the system under various forcing frequencies is examined. For these computations, it is assumed that the system is conservative in that the oscillations neither amplify or decay. With the free vibration analysis, the behavior of the system is examined after the forcing frequency is removed. This method indicates not only the free vibration frequencies but also the amplification or decay characteristics of the system.

In this study, the impedance method was used. However, it was modified so that various damping factors could be included in the analysis. Thus, it is possible to match the terminal impedance and thereby, also, obtain the free vibration characteristics.

Impedance is defined as the ratio of the head variation to the discharge variation. Unfortunately, this definition is not dimensionless and the absolute value of the impedance depends upon the system of units used in the analysis.

The significance of the impedance values can be visualized by examining what happens to a sine wave. If the line is infinitely long, there will be no reflections from the end of the line. The ratio of the head to discharge variation in this line is termed the "characteristic impedance." If reflections occur at various structures in the system, then the resulting wave form consists of both the outgoing and a reflected sinusoidal wave. For some frequencies, these waves will reinforce and at other frequencies, the waves will cancel. If a total reflection occurs, then all of the input energy is stored in the system. This pattern is known as "standing waves." If energy is transferred through the system due to incomplete reflections, then the pattern consists of standing waves and "traveling waves." The traveling waves comprise that portion of the waveform which transmits the energy through the system.

For the Navajo Dam outlet works analysis, the computations proceeded from the reservoir toward the hollow-jet valves. The terminal impedance at each valve is given by:

$$Zv = \frac{2\overline{H}}{\overline{Q}} = \frac{(2)(124)}{1875} = 0.13$$

The characteristic impedance of the line to the valves has a magnitude of 4.8. Since the terminal impedance is less than the characteristic impedance, the hollow-jet valves appear to behave like an open-ended pipe. The significance of this is the discharge and not the head variations will be the greatest at the valves. Therefore, if the system resonates, it will resonate at even harmonics.

The results of the analysis for the outlet works are as follows:

Harmonic	Period (s)	Damping factor
Second	1.14	-0.36
Fourth	0.69	-1.07
Sixth	0.37	-0.30

The damping factor is a measure of how rapidly disturbances in the system decay. The factors having the larger absolute values decay the most rapidly. Thus, from the results, it can be seen that the sixth harmonic is the most likely harmonic to be excited by disturbances in the system.

EXCITATION SOURCES

Air Entraining Vortexes

An air entraining vortex could develop over the intake. The crown of the tunnel immediately upstream of the fixed-wheel gate drops 1150 mm creating a pocket where air bubbles could collect. An intermittent release of large air bubbles from the pocket could excite the outlet works tunnel to resonance as the bubbles pass through the hollow-jet valves.

The formation of an air entraining vortex over the intake structure is highly unlikely. The water surface was 53 m above the bellmouth intake and 17 m above the top of the trashrack structure. The guide vanes on the intake structure and the trashrack bars themselves both tend to dissipate the rotational motion of a vortex. Moreover, the entire reservoir area up to the dam has been given unrestricted access to boaters and fishermen.

The observation of an air entraining vortex would have been noticed earlier and access to the area would have been restricted due to the inherent danger to boaters.

Wave Action

To date, there have been no reported resonance conditions in conduits which can be attributed to excitation by wave action. However, the possibility of wave-excited resonance must always be considered.

Due to the orientation of the reservoir, only those winds from the north to northeast act over a long enough fetch to produce significant waves at the outlet works. These range from an amplitude of 400 mm with a period of 2.6 s at a mean wind speed of 10 m/s to an amplitude of 900 mm with a period of 3.8 s at a mean wind speed of 30 m/s.

The wind records at Farmington, New Mexico, were examined to determine the probable wind direction and magnitudes during May 23. These showed a mean wind velocity of 3 m/s primarily from the east. This would produce a wave height of 50 mm and a period of 1.9 s. At the depth of the intake, waves of this magnitude could not be detected. Therefore, it is extremely unlikely that wave excitation of the outlet works is possible.

SEAL LEAKAGE AT FIXED-WHEEL GATE

Most textbooks on hydraulic transients cite the example of the Bersimis II resonance problem which was caused by a leaky seal. This particular seal was located at the downstream end of a penstock. The seal had the characteristic that increases in head would decrease the discharge. It can be shown that this characteristic at the downstream end of a conduit leads to instabilities.

A similar condition can develop due to leakage at the upstream end of a conduit if the discharge through the seal increases as the head increases. The seals at the fixed-wheel gate have this characteristic and they are leaking (see attached travel report, July 18, 1979). This characteristic alone can be responsible for the resonance. However, various forcing functions at the gate were considered.

One possible forcing function at the gate is due to vortexes shed into the gate recess at the crown of the conduit. The gate at its full-open position forms an opening 580 mm (1.9 ft) perpendicular to the flow and 1300 mm (4.25 ft) with the flow. The conduit height at the gate is 3560 mm (13.0 ft). The proportions give a Strouhal number for the predominant mode of vortex shedding of 1.0. However, shedding at a Strouhal number of 0.6 is also possible.

With the discharge of 106 m^3/s, these Strouhal numbers correspond to frequencies of 11.3 and 6.8 Hz or periods of 0.09 and 0.15 s, respectively.

The gate is positioned by a hoist stem 89 mm (3-1/2 in) in diameter having an unrestrained length of 104 600 mm (343.1 ft). It was felt that excitation of this stem by the variable pressures on the bottom of the gate could cause the stem to vibrate. Two modes of vibration were considered, lateral and axial. The fundamental mode of lateral vibration of the stem has a period of 37.5 s. If the hoist stem and gate vibrate as a mass on a spring, the fundamental mode of this axial vibration has a period of 0.39 s. If the shaft is moving with this latter period, then leakage through the bonnet seals should also vary with about the same period.

OBSERVATIONS

The only excitation source which seems likely for the resonance observations at Navajo Dam is the axial vibration of the hoist stem for the fixed-wheel gate. Its period matches relatively well with the sixth period of vibration of the hydraulic system.

This hypothesis can be tested by setting both hollow-jet valves to a discharge of 106 m^3/s and causing the hoist stem to vibrate by giving it a vertical impulse. If resonance is observed, it can be stopped by changing the flow rate through the hollow-jet valves.

Remedial measures to prevent future occurrences of the resonance would include replacement of the bonnet seals and provision of a dashpot damper on the hoist shaft to restrain its motion.

Henry T. Falvey
by HTK

Copy to: D-222 (Davidson)
D-252 (Gerbig)
D-400
D-1530
D-1531 (Isbester)

DEC-40A (8-70)
Bureau of Reclamation

BUREAU OF RECLAMATION
Engineering and Research Center
Denver, Colorado

TRAVEL REPORT

Code : D-222/D-224/D-1540 Date: June 29, 1979

To : Chief, Division of Design
Chief, Division of Research

From : L. Davidson, A. Bourland, L. Mantei, and R. Sorensen

Subject: Navajo Dam - Inspection by Engineering and Research Personnel

1. Travel period (dates): May 22-24, 1979.

2. Places or offices visited: Navajo Dam and vicinity.

3. Purpose of trip (include reference to correspondence prompting travel):
To inspect dam and to determine the need for horizontal drainage holes into the abutment.
(Verbal Request - Chief, Division of Design)

4. Synopsis of trip:

   a. May 21, 1979: Travel to Durango, Colorado.

   b. May 22, 1979: Meeting with Durango Projects Office personnel and inspection of Navajo Dam. Mr. L. Burton, D-1600, was with the inspection party until 1:00 p.m.

   c. May 23, 1979: Inspection of Navajo Dam; vibration problem noted in outlet works conduit.

   d. May 24, 1979: Return to Denver.

Durango Projects Office Meeting

On the morning of May 22, 1979, between 8:00 a.m. and 9:00 p.m., we met with regional personnel, Messrs. Bob Brewster and C. Rorvik, and briefed Mr. John Brown, Chief of the Durango Projects Office on our purpose. A list of attendees is attached.

Site Examination

On May 22 and 23, we examined Navajo Dam in the company of Mr. Brewster, Mr. [illegible] the dam tender. All seepage areas on the right and left abutments were examined as well as the wet areas on the downstream face.

Vibration Problem in Outlet Works Penstock

On the morning of May 23, while preparing to examine the right abutment intake areas, a surging was noticed in the air ventilation system to the 72-inch penstock. This surging could be distinctly heard in the air inlet pipe and caused vibration of the pipe and the tower adjacent to it. The surging was heard as a very deep throbbing that lasted from 5 to 15 seconds with intervals of silence from 15 to 30 seconds. Bubbling was heard in the air inlet pipe during the silent periods. Air was being sucked into the access well through another pipe at the top of the access shaft and could be heard quite clearly. The following data were reported:

Flow through penstock	3700 ft^3/s (gates 67 percent open)
Reservoir level	6056.07
Penstock pressure	75 lb/in^2

The E&R Center was called and discussion held with Messrs. E. Rossillon, D-223, and R. Kramer, D-222. It was agreed to by all concerned that the flow be reduced until the surging stopped. The flow was reduced to 3500 ft^3/s and the surging immediately stopped.

The time sequence of events surrounding the surging problem is as follows:

a. 10:00 a.m.±: Discover surging.

b. 10:30 a.m. : Called Denver.

c. 10:45 a.m. : Reduced flow - 3700 ft^3/s to 3500 ft^3/s. Gate opening reduces from 67 percent to 54 percent, Penstock pressure increases from 74 lb/in^2 to 90 lb/in^2

d. 10:30 a.m.±: Ed Wood and Leonard Trujillo, who work for the dam tender, checked the gate chamber and confirmed that "vibration was in vent."

e. 10:42 a.m. : (5-15-second throbbing) 15-35-second silence.

f. 10:45 a.m. : Closed gate to 54 percent.

g. 10:50 a.m. : Drove to crest of dam and surging had stopped.

h. 11:45 a.m. : Walked up penstock tunnel to chamber. Gate chamber and penstocks quiet.

Mr. E. Woods and L. Trujillo, who work for the dam tender, walked up the penstock tunnel into the chamber during the vibrations. They felt no vibrations until they entered the chamber. Inside the chamber the fixed wheel gate bonnet and the vent pipe were vibrating heavily. Both men and the dam tender reported that they had never heard these vibrations before and that they were severe vibrations.

5. Conclusions:

a. The current seepage exiting from the abutments presents no safety problem to the dam. It is unsightly but not a threat to the integrity of the dam.

b. The seepage exiting into the type one drains on both the left and right groins is not carrying fines from the embankment and is not a threat to the stability of the embankment.

c. The small seep exiting on the surface of the embankment near R-13, called "hole in the wall," should be traced to its source and channeled into the type one drain. If the seep is coming from deeper within the embankment and not from the sandstone, as suspected, Mr. L. Davidson of the Denver office should be notified by phone, FTS-234-3749.

d. The wet area near the right abutment groin, elevation 5850, contains small clear seeps which are not at this time a threat to the integrity of the embankment. Four slotted-pipe piezometers should be installed in this area to monitor the water surface fluctuations.

e. A shallow ditch, near elevation 5975, in the right abutment has standing water, no water movement was observed. Any change in this condition should be reported immediately.

f. The wet area near the left abutment groin is not at this time a threat to the integrity of the embankment. Four slotted-pipe piezometers should be installed in this area.

g. No other wet areas on the embankment surface were reported or observed.

h. The records for Navajo Dam are spread out between the Farmington Office, the Montrose Office, and the Durango Office. These records should be centralized and stored in one location. Durango, Colorado is recommended due to its proximity to the dam. A list of all available records should be sent to the E&R Center, Attention: D-220.

i. A program of monitoring the main individual seeps, recording their elevations, and channeling their flow to the type one drains through pipes should be instituted as soon as possible. This program is currently being outlined and will be presented for your approval by June 15, 1979. (This was done in a 142 mtg. w/ Jensen)

j. A Mechanical Engineer and personnel from the Spillways and Outlets Section should evaluate the surging and vibration problem as soon as possible.

k. No auxiliary power for operating the gates is available at Navajo Dam. The dam tender has reported that electric power has not been available at the site for periods of up to 8 hours. Auxiliary power should be placed at this site as soon as possible.

l. The series of horizontal drainage holes that was proposed as an intermediary treatment for the right abutment is not required. However, to test the workability of any future horizontal drainage system, we believe five trial-horizontal drainage holes should be drilled into the right abutment rock outcrop at elevation 5850, adjacent to the groin.

m. The adit proposed in the decision memorandum dated March 23, 1979 should not be constructed until it is established that it will adequately serve its main function. This will require several years of data evaluation.

6. Recommendations: None.

Luther W. Davidson
Albert K Bourland
L. Mantei
Raleigh D. Sorensen

Copy to: Power Operations Manager, Page, Arizona
Chief, Curecanti Field Division, Montrose, Colorado
Attention: L. Anderson
Maintenance Supervisor, Navajo Dam, Farmington, New Mexico
Attention: Wayne Everett

Blind to: D-210
D-222
D-224
D-225
D-1500
D-1543
D-1600

LDavidson:ma

MEETING ATTENDEES

Durango Projects Office	May 22, 1979
John Brown	Projects Office
Bob Brewster	Upper Colorado Region
Charles Rorvik	Upper Colorado Region
Luther Davidson	E&R Center - D-222
Al Bourland	E&R Center - D-222
Leo Mantei	E&R Center - D-224
Raleigh Sorensen	E&R Center - D-1543
Lynn Burton	E&R Center - D-1600

I made set of notes: "memo-to-files."

DFC-40A (8-70)
Bureau of Reclamation

BUREAU OF RECLAMATION
Engineering and Research Center
Denver, Colorado

1530

TRAVEL REPORT

Code : D-252, D-1531 **Date:** July 18, 1979

To : Chief, Division of Design
Chief, Division of General Research

From : Lee C. Gerbig and Thomas J. Isbester

Subject: Inspection of Navajo Dam Outlet Works

1. **Travel period (dates):** June 6 through 8, 1979.

2. **Places or offices visited:** Navajo Dam.

3. **Purpose of trip (include reference to correspondence prompting travel):**

To examine Navajo Dam Outlet Works for possible cavitation damage and investigate vibration problems associated with operation of the fixed wheel gate and hollow-jet valves. (Telephone Memorandum from Jack Langford UC-400 to Vern Yocum, E&R Center, D-430 on June 1, 1979.)

4. **Synopsis of trip:** We left Denver on the morning of June 6, 1979, accompanied by Jack Langford, UC-400. We arrived at Navajo Dam early in the afternoon and discussed the operation of the outlet works with the damtender, Wayne Everett, and his assistants, Leonard Trujillo and Ed Wood.

On May 23, a severe vibration was reported which could be felt on the top of the dam adjacent to the fixed wheel gate shaft, and in the gallery near the bonnet cover and air vent. At that time, the reservoir was at elevation 6057, the hollow-jet valves were open about 73 percent and releasing 3750 ft^3/sec. The vibration lasted for 5 to 15 seconds, followed by a cyclic roar in the air vent which lasted about 30 seconds and the process repeated. A time period of about 24 hours at identical hydraulic conditions elapsed before the vibration was triggered. The triggering mechanism for the vibration is not known. The vibration was eliminated by closing the hollow-jet valves to about 54 percent, reducing the discharge to 3500 ft^3/sec.

The dam and outlet works were carefully observed while discharging 3500 ft^3/sec until our arrival on June 6. The reservoir elevation increased 10 feet between the time the vibration was noted and our arrival. The afternoon of June 6, the hollow-jet valves were opened to 73 percent in an attempt to reproduce the vibration condition. No noise or vibration could be detected.

The outlet works was unwatered overnight to allow for inspection of the fixed wheel gate, piping, and hollow-jet valves the following morning. We were joined by Larry Anderson, Chief, Curecanti Field Division, Montrose, Colorado; and Ray Nutter, Civil Engineer, Curecanti Field Division, Montrose, Colorado; who was present on May 23 and observed the unusual occurrence.

No anomalies were found during the inspection which we could relate to the vibration problem. The fixed-wheel gate is in excellent condition except for sizable leaks through the stem packing and bonnet cover. In general, the coating on the interior of the outlet conduit is excellent. Several small areas of cavitation erosion were noted during the inspection. The 30-inch outlet cone had patches of cavitation erosion on both the up and downstream sides. The powerplant header tie rod protective coating was eroded nearly its entire length. The wye branch tie rod had small eroded patches near the top and bottom. Patches of cavitation erosion were noted downstream at the miter joints in the bends upstream at the hollow-jet valves. The hollow-jet valves showed no progression of damage observed during inspection on May 1, 1979.

We connected a recording pressure gage to the bypass line on the fixed-wheel gate for further testing on June 8. Larry Anderson and Roy Nutter left the afternoon of June 7 to return to Montrose.

On the morning of June 8, we closed the 4- by 4-foot outlet gates and examined the auxiliary outlet works tunnel and flip lip for possible damage, and found the entire auxiliary outlet works tunnel to be in excellent condition. We then returned the auxiliary outlet works to service.

We again tried to duplicate the previous vibration in the outlet works by discharging 3750 ft^3/sec through the hollow-jet valves, and again we could not reproduce the problem. We then operated the hollow-jet valves in the full open position, and observed the operation. No unusual vibration or noise was noted. The reservoir water surface over the intake structure was observed to see if a vortex was present. A small disturbance was observed directly over the outlet works intake tower, which remained fixed with relation to the moving wind waves. The disturbance appeared to be about 4 feet in diameter and lasted about 10 to 15 minutes, at which time the wind direction changed and the disturbance disappeared.

We left Navajo Dam on the afternoon of June 8.

A detailed report of the examination of the outlet works is included in Appendix A.

5. Conclusions: The outlet works, including the fixed-wheel gate, piping ring-follower gates and hollow-jet valves were in satisfactory condition, except for the leaks in the fixed-wheel gate bonnet cover and stem packing.

The auxiliary outlet works is in excellent condition, and it appears that the modifications and repairs are performing very well.

The vibration and noise observed earlier and reported to the E&R Center in

Denver, could not be induced at this time.

In the event of subsequent vibration problems, field personnel were advised to document gate openings, reservoir water surface elevation, discharge, and any unusual reservoir water surface appearance, pulsing of the air vent, and pulsing of leakage through the bonnet cover, etc.

At the earliest opportunity, the leaks in the fixed-wheel gate bonnet cover and stem packing should be repaired. The interior of the outlet works pipes should be repaired and should be painted in the cavitated areas when the outlet works can be unwatered for the necessary length of time. The cavitation damage on the 72-inch hollow-jet valves should be repaired before the damage becomes serious.

6. Recommendations: None.

Lee C. Gerbig
Thomas J. Isbester

Enclosure

Copy to: Regional Director, Salt Lake City, Utah Attention: 400
CRSP Operations Field Division, Montrose, Colorado
Durango Projects Office, Durango, Colorado Attention: 400
Chief, Division of O&M Technical Services, E&R Center

Blind to: D-210
D-223
D-250
D-252
D-253
✓D-1530
D-1531
D-1500

LCGerbig:pm

AUG

NOTED:
E. M. Tomsic
ACTING
Chief, Division of Design

Noted AUG 8 1979
ACTING
BERNARD A. SILVERMAN

APPENDIX A

The gate chamber for the fixed-wheel gate was examined shortly after our arrival at Navajo Dam on the afternoon of June 6. There is considerable leakage between the bonnet and bonnet cover, on the downstream side, near the gate centerline. The bonnet cover was removed during the past year to paint the gate leaf, and apparently the gasket was installed incorrectly.

The gate stem packing also leaks considerably. The packing did not leak prior to the repairs done last year. Either the packing was damaged or installed improperly. It was noted that the two-piece packing gland was installed with the split in the gland alined with the split in the bonnet cover, rather than being rotated 60 degrees as shown on the drawings.

The total leakage from both areas is estimated to be approximately 1/2 ft^3/sec. The bonnet cover is otherwise in satisfactory condition. The area in the gate chamber is very wet and difficult to maintain.

The outlet works was unwatered on the morning of June 7 for examination of the fixed-wheel gate, pipe interior, ring-follower gates, and hollow-jet valves.

The fixed-wheel gate is in excellent condition. The gate leaf was recently painted, and the gate leakage was quite acceptable. The operation of the gate was reported to be quite smooth, with no unusual characteristics noticeable.

The interior of the 110-inch outlet pipe was in excellent condition. There were 8 to 10 eroded spots near the expansion couplings. The spots appear to be galvanic cell action between spacer blocks and the pipe and did not appear to be serious. The spots were 3 to 4 inches wide, 1 to 2 inches long, and 3/16 to 1/4 inch deep.

The conic section at the branch to the 30-inch hollow-jet valve had cavitation eroded areas on the upstream (right) and downstream (left) sides. The erosion on the right side began about 13 inches into the cone and covered a circular patch of about 12 inches in diameter, on an angle of about 45 degrees below the outlet transverse centerline. The erosion on the left side began just into the cone on the transverse centerline, and covered a circular patch of about 4 inches in diameter. Near the downstream end of the cone on the invert, a very rough, lumpy section of coating was found. This coating should be ground smooth to prevent triggering cavitation in the 30-inch conduit. The cavitation in the 30-inch pipe entrance is probably due to the operation of the 72-inch and 30-inch hollow-jet valves simultaneously as noted in the travel report dated June 5, 1979.

The powerplant header tie rod had large areas of protective coating removed, but very little metal damage has occurred. The wye branch tie rod had small patches of coating removed at the top and bottom. The mitered bends in the bifurcation to the 72-inch hollow-jet valves showed some cavitation damage of the inside of the bends. The cavitation damage is typical for mitered bends, but it is exaggerated by the welds which protrude into the flow. The welds at the mitered joints protrude 1/16 to 1/8 inch beyond the pipe, and the cavitation damage is immediately downstream of the welds. The damage is not very serious at this time, but before the pipes are repaired and repainted, the welds should be ground for a smoother contour. The mitered bend for outlet No. 1 is cavitated a little more than outlet No. 2.

The stub outlet for the powerplant showed no damage and was in excellent condition. There was a small spot of cavitation at the upstream edge of the ring-follower gate No. 1, apparently due to slight misalinement between the gate body and the gate leaf in the horizontal direction with the gate fully open. The hollow-jet valves were examined, and they appeared to be in satisfactory condition. The cavitation noted on the examination on May 1 has not progressed, and the valves have been functioning satisfactorily.

The 30-inch hollow-jet is in excellent condition, with no obvious cavitation.

The auxiliary outlet works was unwatered for examination of the discharge tunnel and downstream portion of the 4- by 4-foot outlet gate. The outlet gate vibrated considerably the last time it was closed under a high head, and there was some concern about closing it again. Before the gate was operated, the top seal was well lubricated. The gate was stopped at one foot intervals, and the top seal was lubricated at each interval. The outlet gate closed very smoothly with no vibration or chatter, and the hydraulic pressure did not fluctuate. The guard gate was then closed prior to examining the discharge tunnel.

The auxiliary outlet works tunnel was in excellent condition. There were no signs of damage due to operation at very high reservoir levels. A rough spot was observed in the floor, approximately 3/4 of the length down the tunnel, but it has not deteriorated within the last month of operation. The auxiliary outlet works was examined one month ago, prior to placing it into service, and it was reported that there was no change to the tunnel since that examination.

The air slots and area just downstream of the outlet gate are in excellent condition. The metal gate frame had some very slight cavitated areas and some torn and loose protective coating. Loose flaps of protective coating were removed with a pocket knife.

Overall the condition of the outlet works and auxiliary outlet works is satisfactory and should not cause any operating difficulties.