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Operation of Glen Canyon Dam Spillways - Summer 1983

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Abstract. - Flood control at Glen Canyon Dam is provided by a 41-ft (12.5-m) diameter tunnel spillway in each abutment. Each spillway is designed to pass 138 000 ft^3/s (3907.7 m^3/s). The spillways first operated in 1980 and had seen very little use until June 1983. In early June the left spillway was operated for 72 hours at 20 000 ft^3/s (566.3 m^3/s). After hearing a rumbling noise in the left spillway, the radial gates were closed and the tunnel was quickly inspected. Cavitation damage had occurred low in the vertical bend, resulting in removal of approximately 50 yd^3 (38.2 m^3) of concrete. Flood flows continued to fill the reservoir. Both spillways were operated releasing a total of 1 626 000 acre-ft (2.0 x 10^9 m^3) over a period of 2 months. Extensive cavitation damage occurred in both spillways in the vicinity of the vertical bend.

Introduction. - The tunnel spillways are open channel flow type with two 40- by 52.5-ft (12.2- by 16.0-m) radial gates to control releases to each tunnel. Each spillway consists of a 41-ft (12.5-m) diameter inclined section, a vertical bend, and 1000 ft (304.8 m) of horizontal tunnel followed by a flip bucket. Two other Reclamation spillways with generally similar configurations had experienced damage during their initial operation. In 1941 the Arizona tunnel spillway at Hoover Dam suffered severe damage to the liner and underlying rock requiring extensive repair. In 1967 the tunnel spillway at Yellowtail Dam had less severe damage after 10 days of operation at 15 000 ft^3/s (424.8 m^3/s). To prevent future damage at Yellowtail an aeration slot was developed after extensive model studies and installed when the tunnel was repaired. An aeration slot design for the Hoover tunnel spillways is presently under study.

An analysis of the spillway flow at Glen Canyon Dam indicated the need for an aeration slot similar to the successful design used at Yellowtail Dam. The project had gathered the necessary field data to begin the slot design when the spillways were required to pass the summer flood of 1983 on the Colorado River.

Glen Canyon Dam Releases June and July 1983. - Runoff in the upper basin of the Colorado River was steadily increasing in late May. Figure 1 shows the operation of the waterways from May 21 to August 10, 1983. On June 2 the left tunnel spillway gates were opened to release 10 000 ft^3/s (283.2 m^3/s). By June 5 the gates were further opened to release 20 000 ft^3/s (566.3 m^3/s). Early in the morning of June 6 loud rumbling noises

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were heard coming from the left spillway. That afternoon engineers inspected the tunnel and found several large holes in the invert of the vertical bend. The damage was initiated by cavitation which had formed as a result of a calcite deposit 0.25 in (0.64 cm) high on the tunnel invert at approximately Sta. 25+00. Four-foot (1.2-m) high plywood flashboards were immediately installed on top of the four spillway gates. By June 8 it was clear that both spillways would have to be used to pass the flood without overtopping the spillway gates. An analysis of the potential for cavitation damage in the tunnel spillways indicated that if the releases could be held below 6000 ft^3/s (169.9 m^3/s), it would take several months of operation to produce serious damage. The fact that the left spillway was already seriously damaged and continued high inflows into Lake Powell would force higher releases through the spillways prompted a decision to continue to use the left tunnel spillway and reserve the right spillway (maintain releases of 6000 ft^3/s or less) should the need for its use arise in the future. In making the decision to increase the discharge through the left spillway, it was recognized that the invert of the vertical bend and downstream tunnel would be seriously damaged. It was also recognized that the spillway flip bucket would eventually be unable to flip the jet as the velocity decreased due to increased damage, with time, along the tunnel invert. However, it was hoped that this action would direct the high energy jet downstream along the tunnel centerline producing damage in the horizontal tunnel away from the tunnel plug.

From June 16-23, the discharge through the left tunnel spillway was increased as needed from 12 000 to 23 000 ft^3/s (339.8 to 651.3 m^3/s) to ensure a continued flip from the tunnel bucket, figure 2b. This operational plan proved successful and provided an additional 16 days of "productive life" for the right spillway. To increase storage capacity in Lake Powell and continue controlled releases through the spillways, 8-ft (2.4-m) high metal flashboards were designed and used to replace the wooden flashboards on top of the gates. Analysis indicated that 8-ft flashboards would only marginally overstress the gates. This was acceptable on a temporary basis. The metal flashboards provided an additional 1.3 million acre-ft (1.60 x 10^9 m^3) of storage in Lake Powell. The flashboards proved to be very useful on the downside of the hyrdograph when the spillway gates were closed on July 23 with a reservoir El. 3707.8 (EL 1130.0), some 7.8 ft (2.38 m) - 1.25 million acre-ft (1.5 x 10^9 m^3) - above the top of the gates.

On June 27 the inflow to Lake Powell reached 111 500 ft^3/s (3157 m^3/s). It was clear that the flood peak had reached a new high and that the total discharge from Glen Canyon would have to be increased. Discharge from the left spillway was increased to 25 000 ft^3/s (707.9 m^3/s) at 7 p.m. In the morning of June 28, the noise level had dramatically increased in the left tunnel, producing a heavy thumping noise on top of the dam. At 9 a.m. the left tunnel spillway flow was increased to 32 000 ft^3/s (906.1 m^3/s) and the right tunnel remained at 15 000 ft^3/s (424.8 m^3/s). Within 50 minutes the left spillway bucket suddenly stopped flipping the jet and the water downstream from the spillway bucket turned an ominous amber color as the jet carried chunks of concrete and sandstone into the river. The spillway flow on the left side was immediately reduced to 20 000 ft^3/s (566.3 m^3/s) with the hydraulic jump again in the tunnel. The right spillway was increased to 27 000 ft^3/s (764.6 m^3/s). Four days later, July 1, rumbling noises were heard coming from the right spillway tunnel. The discharge was lowered to 20 000 ft^3/s and the jet continued to flip on the right side.

On July 7, with the reservoir elevation at El. 3707.5 (EL 1130.0), the spillway gates were closed and the inclined section and vertical bend of each tunnel were inspected. Major damage had occurred in the vertical bend of both spillways. Reinforcement steel which looked like "spaghetti" was observed extending from the damaged tunnel liner in the horizontal section of the right spillway. It was decided that even in the damaged condition, the spillways would be capable of passing 7500 ft^3/s (212.4 m^3/s) each permitting a total release equal to the reservoir inflow. On July 15 Lake Powell water surface elevation peaked at El. 3708.34 (EL 1130.3).

Throughout the period of high flood releases, the four 96-in (2440 mm) hollow-jet valves and the eight power units operated 24 hours a day releasing 44 000 ft^3/s (1245.9 m^3/s) without incident. The excellent performance of this equipment was crucial to the successful operation of flow releases at Glen Canyon Dam during the summer of 1983.

Tunnel Spillway Damage. - In early August the tunnel spillways were dewatered and engineers entered the tunnels from the downstream flip buckets. Upon entering the left tunnel it was obvious that serious damage had occurred. There was approximately 300 yd^3 (230 m^3) of concrete, reinforcing steel, and sandstone in the flip bucket. Once inside the tunnel the first 200 feet (60 m) were relatively free of debris. A large sandstone boulder, 8 by 15 by 15 ft (2.4 by 4.6 by 4.6 m), was found in the tunnel invert some 500 ft (150 m) upstream from the bucket. Debris several feet deep was found in the invert of the tunnel downstream from the boulder. Except for some debris immediately upstream from the boulder, the invert to the vertical bend was relatively clean. Extensive damage had occurred in the vertical bend from approximately Sta. 23+90 through Sta. 26+90. Immediately downstream from the P.T. of the vertical bend, a hole 35 ft (10.7 m) deep, 134 ft (40.8 m) long, and 50 ft (15.2 m) wide had been excavated in the sandstone by the high energy flow. Three-fourths of the tunnel liner circumference had been removed in the area of the deep hole, figure 3.

Inspection of the right tunnel spillway revealed less damage. There was very little debris deposited in the tunnel invert. However, a large hole was found in the tunnel invert immediately downstream of the bend P.T. The invert liner was removed for some 175 ft (53 m) and sandstone had been excavated up to 12 ft (3.6 m) deep.

Conclusions. - The operational experience gained at Glen Canyon Dam during the summer of 1983 has led to increased understanding of the damage caused by cavitation formation in high velocity flow. An air slot has been designed and laboratory tested to solve the problem. Repairs and installation of the air slot in each tunnel are scheduled for completion before the 1984 runoff season. Following is a summary of the conclusions or "lessons learned" from the 1983 experience at Glen Canyon.

1. The cavitation damage potential for a specific waterway can be analyzed to determine if damage will occur and, if so, what ranges of operation are less susceptible to damage producing cavitation.

2. After thorough consideration of negative impacts and assurance of safety of gate design, the use of gate flashboards in emergencies may be very desirable. At Glen Canyon Dam the flashboards permitted relatively small controlled spillway releases from June 10 through July 23 as well as early closure of the spillway gates with approximately 1.2 million acre-ft (1.48×10^9 m^3) of additional storage in the reservoir.

3. For the particular situation at Glen Canyon Dam it proved beneficial to maintain the jet flip from the tunnel spillway flip bucket as long as possible. This operation provided a means of observing the spillway jet to detect tunnel invert deterioration and it also prevented formation of a hydraulic jump in the tunnel as long as possible.

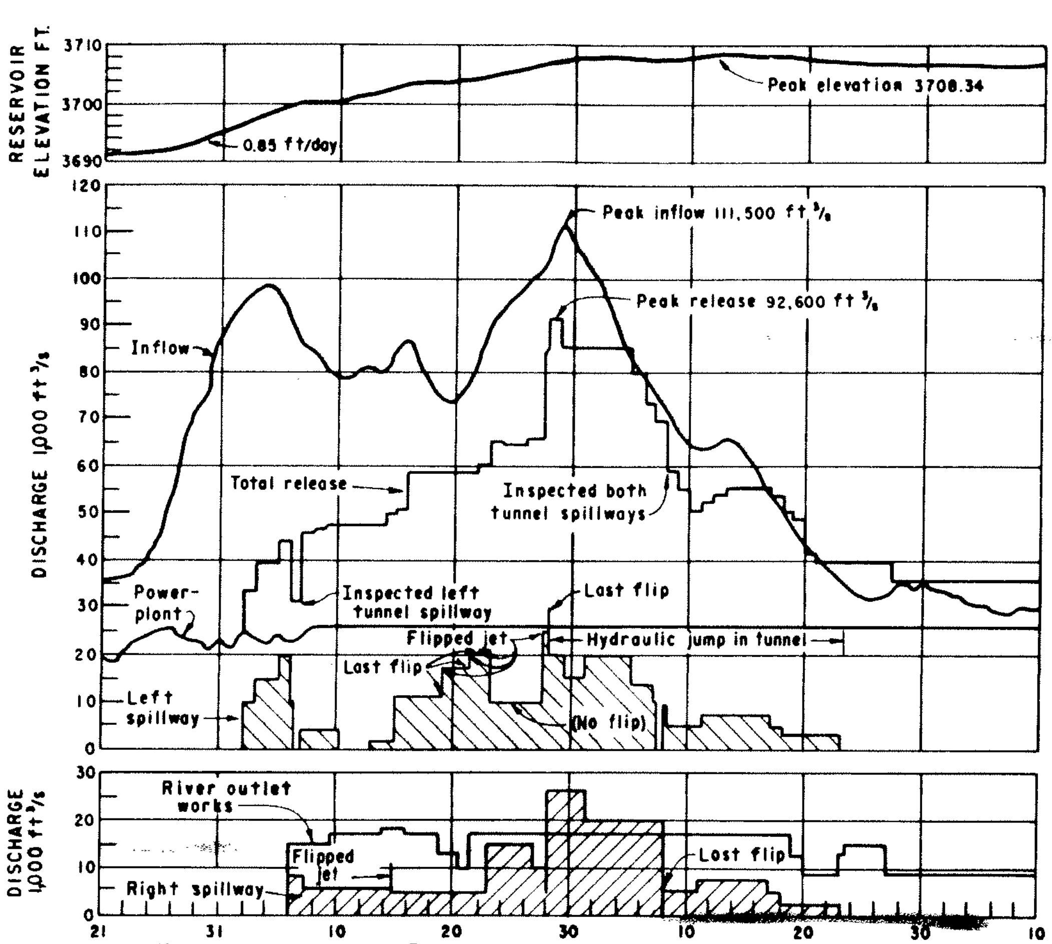

Figure 1 Operation of waterways
May-August 1983.

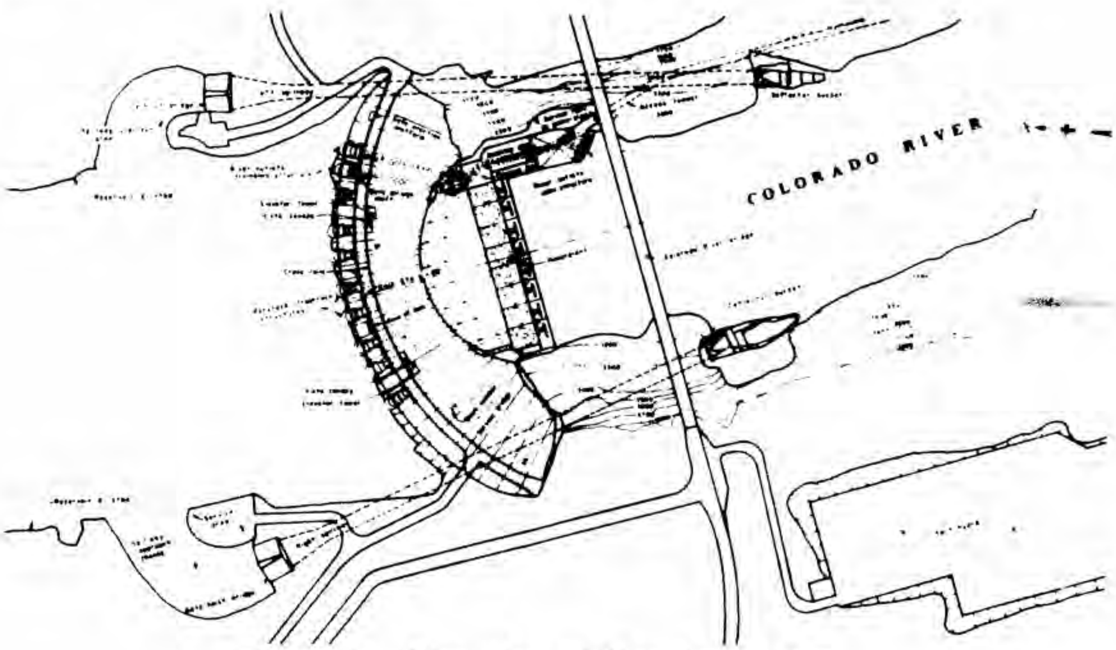

Figure 2a Plan view of Glen Canyon Dam.

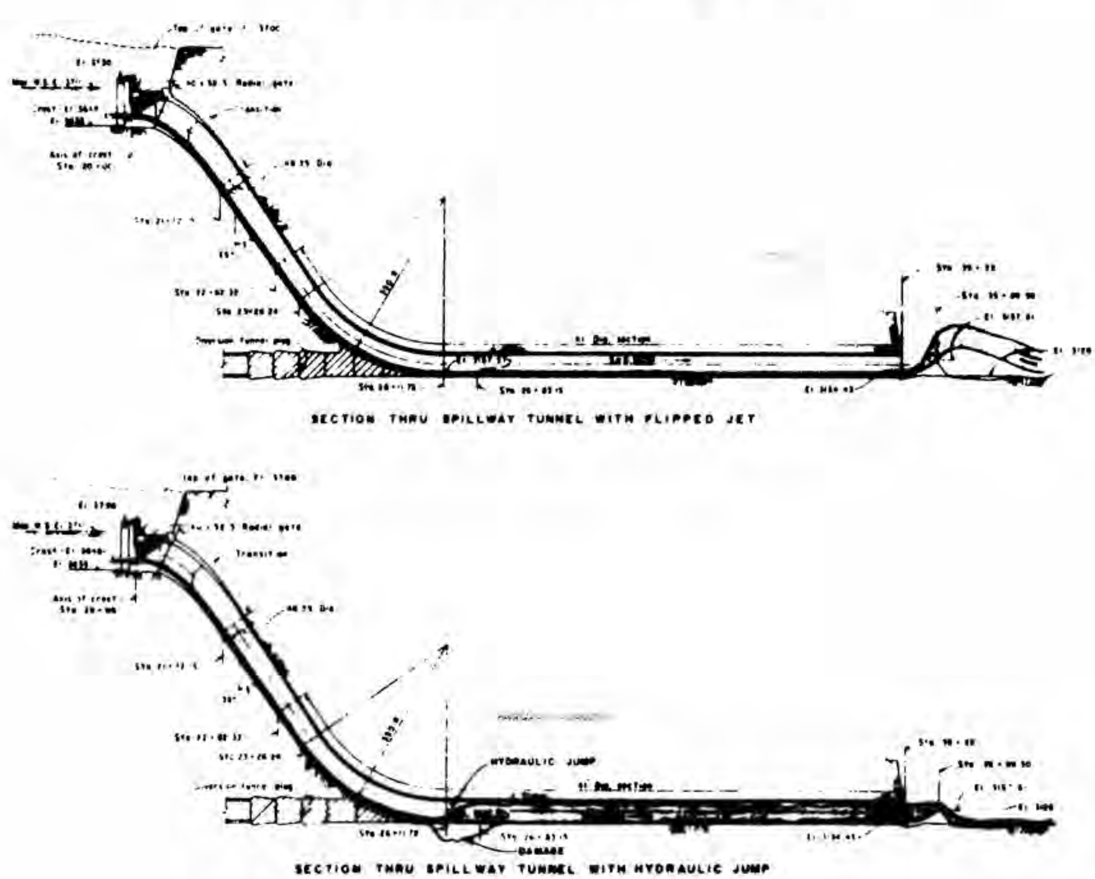

Figure 2b Elevation view of tunnel spillway.

a. View looking upstream across flooded hole at cavitation damage in the vertical bend. Note that the tunnel liner has been removed well above the springline August 1983.

b. View looking downstream across the 35-ft-deep hole in the invert liner at base of the vertical bend. September 1983.

Figure 3. - Glen Canyon Dam left tunnel spillway.