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Prototype Tests of an Emergency Gate Closure

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ABSTRACT

Tests were performed on the outlet works of Silver Jack Dam. The tests were designed to gain information and data on the closure of an emergency gate under unbalanced head conditions. Data were collected with two different data acquisition systems: (1) a microcomputer controlled scanner and (2) a multichannel magnetic tape recorder. Tests were run at three levels of head unbalance and the data which were collected included: emergency gate position as a function of time, forces on the gate leaf, pressures in the conduit downstream from the emergency gate (both static and dynamic), accelerations on the exterior of the conduit downstream of the emergency gate, and air demand through the automatic air-vacuum release valve. The tests were valuable from an operations and maintenance standpoint as well as for providing data for calibration of a mathematical model used to size air valves. Results of the tests allowed for standardization of a test to evaluate gate hoist capacity and air-valve performance for the Safety of Dams program.

INTRODUCTION

Hydraulic tests were performed on the outlet works of Silver Jack Dam (1). The dam, completed in 1971, is a zoned earthfill embankment located on the Cimarron Creek near Montrose, Colorado. The outlet works feature a 2.75-foot by 2.75-foot emergency gate which feeds a 38-inch conduit. About 500 feet downstream from the emergency gate, the conduit bifurcates and terminates with twin 2.25-foot by 2.25-foot control gates. The emergency gate is moved only under balanced head conditions for normal operation; however, occasions may arise in which the emergency gate must be closed under unbalanced heads, i.e., failure of the downstream conduit, malfunction of a control gate, etc. Under these conditions, low pressures will be present downstream from the emergency gate. These low pressures in turn may cause damage or collapse of the conduit. Due to these reasons, most emergency gates are equipped with an automatic air-vacuum release valve. If properly sized and in good operating condition, an automatic air-valve can allow air into the conduit to relieve the low pressures. Silver Jack Dam outlet works were equipped with such a valve, and in addition, due to the combination

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of conduit size and the elevation of the structure, the conduit's collapse pressure (-33 feet of water) exceeded the magnitude of vapor pressure (-24 feet of water).

The emergency gate has a typical 45° sloped bottom seat with no upstream skin plate, figure 1. The automatic air valve is plumbed into the downstream gate frame through a manifolded series of holes in the top of the frame. The 4-inch air valve is a float-type, figure 2.

The data were collected on two separate occasions. The first test was in October 1986, the second in May 1987.

THE TESTS

The test procedures followed were identical for both tests. The balanced head tests included raising and lowering the emergency gate with the downstream control gates closed and the conduit between the emergency gate and the control gates full and at reservoir head.

The unbalanced head tests were done at three different levels of imbalance. With reference to the emergency gate area, the control gates were symmetrically set to provide openings of 33 percent, 67 percent, and 100 percent. The test began with the emergency gate fully open, the control gates set to the desired opening, the flow was allowed to reach a steady state, and then the emergency gate was closed. The rate with which the gate closes is dependent on several factors, including condition of the hydraulic operating system, configuration and condition of the gate leaf and frame, temperature, and water surface elevation in the reservoir. The rates were 0.67 ft/min for test 1 and 0.34 ft/min for test 2.

MEASUREMENTS AND RESULTS

During the balanced head test, the only measurements made were emergency gate position and the high and low side pressures in the operating cylinder of the gate hoist. The emergency gate position was monitored with a string transducer. This transducer gives an output of voltage that is proportional to displacement. The internal pressures in the hydraulic cylinder on the gate hoist were monitored with two pressure transducers, one on the high pressure side of the piston, and one on the low pressure side. By knowing the piston and cylinder areas, the net force acting on the gate could be calculated from these two pressures, assuming minimal friction in the cylinder itself.

The unbalanced head tests were much more measurement intensive. Along with gate position and cylinder pressures, static and dynamic pressures were monitored in the conduit at several locations downstream from the emergency gate. These measurements were done with diaphragm-type static cells and piezoelectric dynamic cells. In addition, accelerometers were mounted on the exterior of the conduit to measure vibration. Air inflow was monitored for all tests using a pressure transducer on the air valve. The air valve and transducer configuration had been previously calibrated in the laboratory.

The balanced head tests yielded no surprises; however, many interesting facts about the condition of the gate leaf and frame were learned from the test. Figure 3 shows net force on the gate leaf for both raising and lowering of the gate. By reviewing this figure, one can see that the data are symmetric about the submerged weight of the gate (1,400 pounds). The sloping linear behavior is due to a constantly changing frictional force. This change is due to the gate movement out of the gate slots and into the bonnet section. In the bonnet section, only a downstream seat exists while in the gate slots, both upstream and downstream seats are present.

The data from the unbalanced tests are presented in three sets: (1) forces on the emergency gate leaf, (2) static pressures in the 38-inch conduit, and (3) air demand through the 4-inch automatic air valve.

The forces on the gate when the head is unbalanced are shown in figure 4. The forces reflect the relative position of the gate leaf regarding upthrust and downpull.

Pressures in the conduit downstream from the emergency date are shown in figure 5. The levels show that the conduit is exposed to vapor pressure for quite a period of time. This ties in well with the air demand data (fig. 6) which indicated small amounts of air entering the conduit with large fluctuations.

These results were somewhat surprising since air should have been entering the conduit to relieve the low pressures. Inspection of the air valve and intake manifold showed that the manifold (fig. 7) which distributes air behind the gate into the conduit was nearly plugged shut. It was estimated that the open area was reduced from the design value of 11 in^2 to 2.7 in^2. The holes were cleaned as much as possible and a test rerun. Figures 8a and b show the pressures and air demand behaved more as first expected. Vapor pressure was not reached and the air demand increased and was much more stable.

The dynamic pressure fluctuation and accelerations of the conduit were recorded in an effort to estimate the speed of the moving hydraulic jump present during the gate closure. During the first test at fully unbalanced head with a gate closure rate of 0.67 ft/min, the front of the hydraulic jump was moving at a rate of about 2.1 ft/s. The emergency gate closed before the conduit was able to vent from the downstream end. However, after the air intakes had been cleaned, the hydraulic jump moved at 3.7 ft/s and when combined with the slower closure rate, the hydraulic jump exited the conduit allowing air to enter from the downstream end.

CONCLUSIONS

Prototype tests are a valuable tool in understanding the complex phenomena which often exists in the operation of hydraulic structures. The use of a varied set of transducers is a definite benefit.

Prototype testing, while generally expensive, often proves to be a valuable and economical solution to a variety of operations and maintenance problems which may be unforeseen in model tests or computer simulations. Testing can also point out scale effects in hydraulic scale models and allow for improved full scale predictions in future physical and mathematical models.

REFERENCE

1. Frizell, K. W., "Emergency Gate Closures - Summary Memorandum Report 1985-1987," Internal Memorandum, Bureau of Reclamation, June 1988.

CONVERSIONS

$1 \text{ ft} = .3048 \text{ m}$

$1 \frac{\text{lb}}{\text{in}^2} = 6894.757 \text{ Pa}$

$1 \text{ lb} = .45359 \text{ kg}$

$1 \text{ in} = 25.4 \text{ mm}$

$1 \text{ in}^2 = 645.16 \text{ mm}^2$

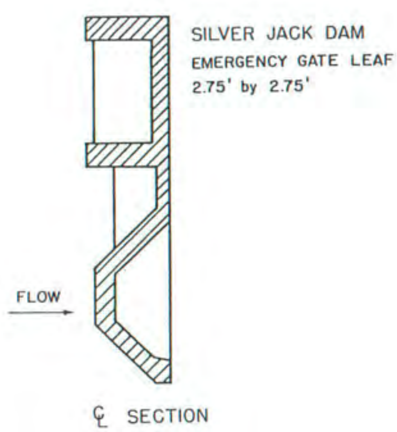


Figure 1. - Section of the gate leaf at Silver Jack Dam.

Figure 2. - 4-in air-vacuum release valve.

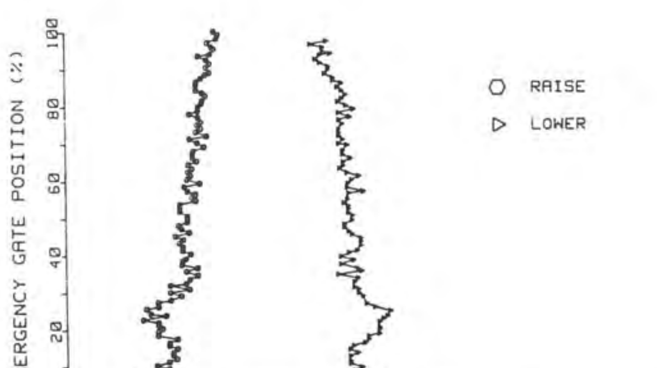


Figure 3. - Forces on the emergency gate - balanced head conditions. A positive net force is in the downward direction.

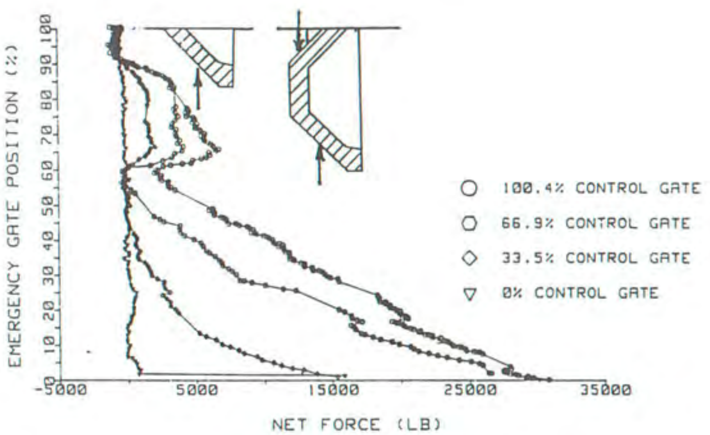


Figure 4. - Force on the emergency gate leaf - unbalanced head operation.

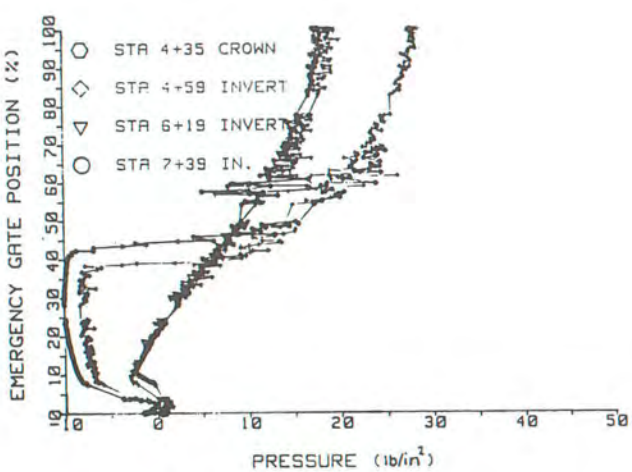


Figure 5. - Pressures downstream from the emergency gate in the 38-inch conduit.

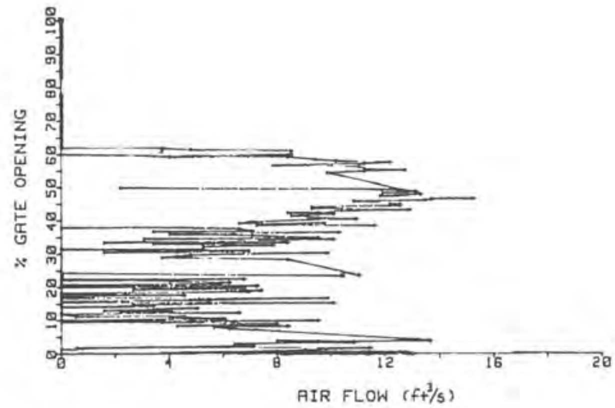


Figure 6. - Air demand at a 100 percent unbalanced head condition.

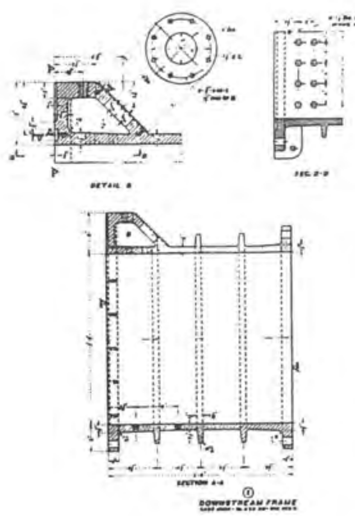
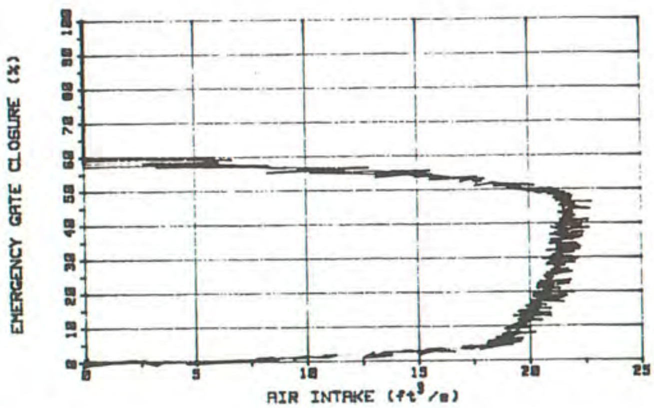
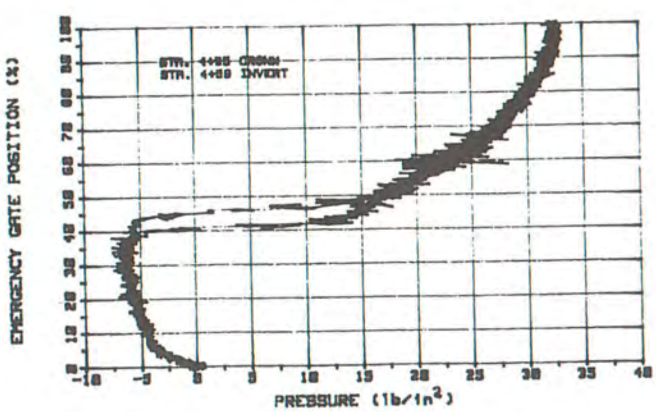


Figure 7. - Detail of the air distribution manifold in the downstream gate frame of the emergency gate.



a. Conduit pressures downstream from the emergency gate.



b. Air demand at a 100 percent unbalanced head condition.

Figure 8. - Pressure and air demand after cleaning of air intake manifold.