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DEVELOPMENT OF TEST PROCEDURES FOR UNBALANCED HEAD OPERATION OF SLIDE GATES

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by

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Development of Test Procedures for Unbalanced Head Operation of Slide Gates

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Abstract

This paper will discuss the steps taken by the Bureau of Reclamation to develop a standardized procedure for testing unbalanced head operation of high-pressure slide gates for outlet works at dams. Largely driven by a Safety of Dams requirement, the test procedures evolved from an extensive review of literature, a hydraulic model study, and two field tests of prototype installations. The test procedures, now instituted, are simple to carry out and are part of regularly scheduled inspections. There is currently a program to extend the test procedures to include different types of gates, such as fixed-wheel and ring-followers.

Introduction

In response to a safety of dams requirement that all guard gates be routinely tested under emergency conditions (unbalanced head), Reclamation reviewed all of their facilities to identify possible problems and begin development of some type of test procedures. Using a quasi-steady state computer model, we evaluated all guard gate installations which were not short-coupled (separated by more than 5 diameters from the controlling gate or valve). We found many deficiencies, particularly in air valve capacity downstream from the guard gates. If there is insufficient air valve capacity during an emergency closure, the outlet pipe could be damaged or totally collapsed due to low (vacuum) internal pressures. Memorandums were written notifying each project whether their outlet works were adequate, whether they needed increased air capacity, or whether stiffener rings needed to be added to the outlet pipes. This last recommendation came only when it was determined that at some sites, it would be impossible to supply the air needed to prevent collapse of the pipeline during an emergency closure.

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The task of developing a test procedure to satisfy the dam safety requirement still needed to be addressed. The Hydraulics Branch completed a series of investigations aimed at developing this test procedure. Investigations included a hydraulic scale model of an outlet works, laboratory tests on a 4-inch air valve, and two field tests to verify expected results and check the test procedure. In addition, an upgraded mathematical model was written which predicts air demand and sizes air valves for typical outlet works installations. The slide gate was chosen first, due to the fact that a high percentage of Reclamation facilities in question use slide gates as guard gates. In developing the test procedure, both old (pre-1940's) and new designs for high pressure slide gates were considered, figure 1.

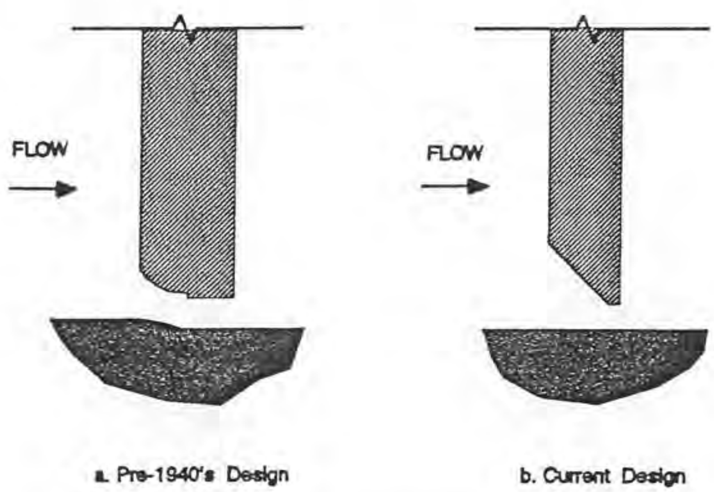

Figure 1.-Typical slide gate leaf designs used by the Bureau of Reclamation.

Investigations

a. Hydraulic Model Study. - A 1:12 scaled hydraulic model of the outlet works at Cedar Bluff Dam was studied. This structure contained a pre-1940's slide gate that was not close-coupled. We measured air demand, pressures on the gate leaf and surrounding frame and static and dynamic pressures in the conduit between the guard gate and the control gate. These data were collected for two different closure rates and all data were related to guard gate position and control gate opening.

Test results revealed that there was significant air demand required by the conduit downstream from the guard gate, figure 2. The air demand was not strongly dependent on the rate of closure, however the rate did slightly alter the guard gate position at which air was first pulled in through the vent. The air capacity seemed to be most influenced by the geometry of the air valve and associated piping (i.e. head losses). The main effect of the rate of closure was on the movement of the hydraulic jump in the conduit and whether it was able to exit the long outlet pipe prior to the guard gate closing. At fast closure rates, the jump will not exit the

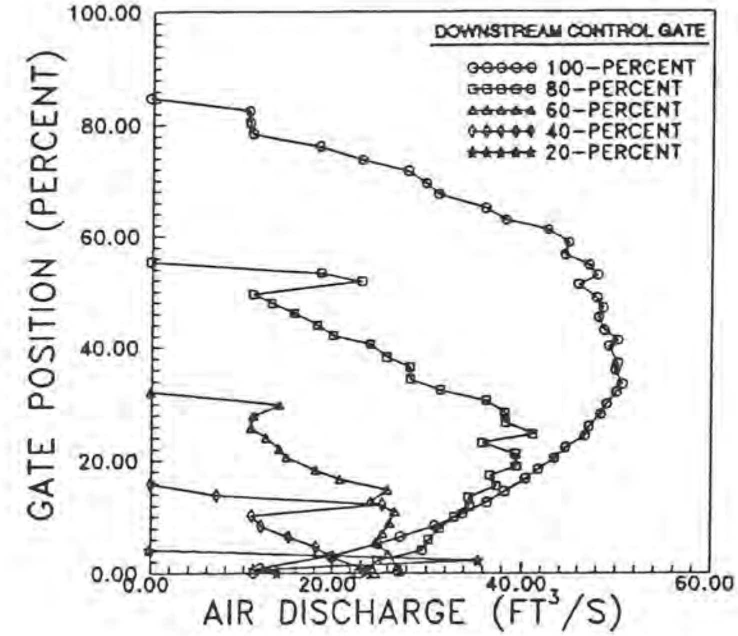

Figure 2.-Model data showing air demand for a 1 ft/min closure rate of the guard gate with various levels of imbalance (control gate position).

conduit before the gate closes and a return wave will travel upstream and impact on the downstream side of the guard gate. As with most guard gate designs, this is not a desired condition. However at most prototype facilities, the closure rates are slow enough that this will not occur, assuming that the air valves are properly sized.

The losses in an air valve are generally presented by the manufacturer in terms of a discharge coefficient ($C_d = Q/(2g\Delta H)^{1/2}$). We checked the coefficient of discharge of air flow into a typical 4-inch prototype air vacuum-release valve (and found that the values compared to within about 10-percent of the manufacturer's information. We measured a coefficient of 0.44 and the manufacturer's literature reported a coefficient of 0.4. These losses generally dominate the overall loss term when evaluating the discharge capacity of a given air valve installation.

We also measured the pressure distribution on the gate leaf, figure 3. The distribution relates to the hydrodynamic loading on the gate leaf (i.e. downpull, downthrust and upthrust) and in turn, to the loading that the gate hoist will experience. In addition to the hydrodynamic forces, there are frictional forces due to the guides and/or seating surfaces. Estimating the frictional forces is not a difficult procedure; the main variable is the value of the coefficient of friction. Using model data and estimating frictional forces, a curve showing total force required to move the gate as a function of gate position can be plotted. As figure 3 shows, for a scaled up prototype gate, a large portion of the underside of the gate leaf is subject to vapor pressure for gate positions between 10 and 95 percent.

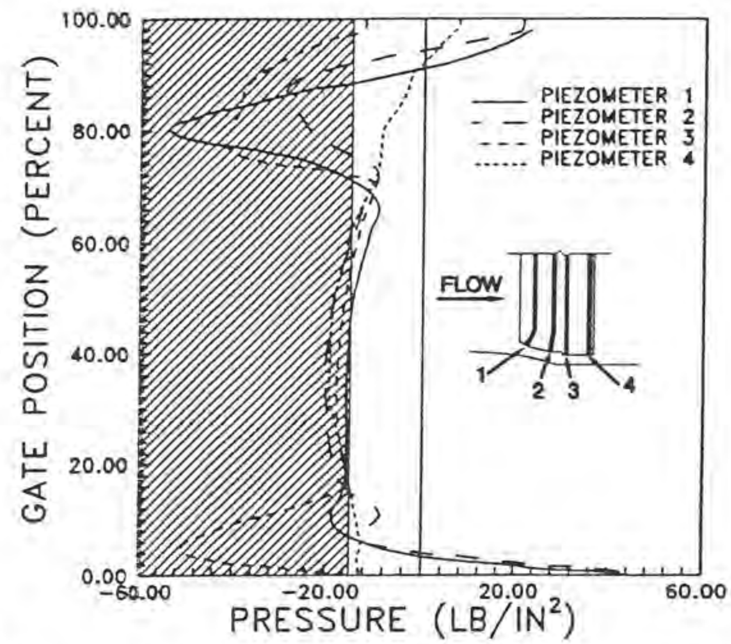

Figure 3.-Model results of the pressure distribution on the gate lip during a fully unbalanced closure. Hatched area represents scaled vapor pressure.

Since the maximum frictional load occurs as the gate is just broken free and begins to open, these tests indicate that the maximum total force required occurs between 10 and 20 percent open.

The main objective for a field test of an unbalanced gate closure is to verify that the hoist capacity is adequate to both open and close the guard gate with unbalanced head conditions. If the guard gate is opened at least 20 percent, the hoist capacity should be tested under maximum emergency conditions. The main purpose of the air valve is to relieve the subatmospheric pressures in the conduit downstream from the guard gate. Depending on the conduit design (material, diameter and wall thickness) the collapse pressure p (lb/in^2) of a steel pipe above ground can be calculated using:

$$p = 50{,}200{,}000\left(\frac{t}{D}\right)^3$$

where t is the thickness of the pipe shell (inches) and D is the inside diameter of the pipe (inches). It is possible that with the right combination of pipe diameter and wall thickness, the collapse pressure can not be reached in some instances. However, there are many existing structures which would collapse without the relief that an air valve provides. It is for this reason that care must be taken when a structure is exposed to these kinds of conditions.

b. Prototype Field Tests. - The first field verification of the initial test procedures was carried out at Silver Jack Dam outlet works in Colorado in 1988. This site was chosen because the design collapse pressure of the conduit downstream from the guard gate was in excess of what was available. This fact allowed us to perform a full unbalanced closure without the fear of possible collapse. The 2.75- by 2.75-foot guard gate was located approximately 500 ft upstream from a pair of 2.25- by 2.25-foot control gates. The guard gate was of the post-1940's design (fig. 1b) and was equipped with a 4-inch air vacuum-release valve just downstream from the guard gate leaf.

We ran several tests, including full closures with balanced heads to fully unbalanced heads, in addition, we ran the proposed test procedure developed from the laboratory study. The tests went smoothly and we collected pressures and air demand data during each test. Back at the laboratory, we analyzed the test data. With fully unbalanced heads, instrumentation showed very small and erratic air demand. The corresponding conduit pressures revealed that vapor pressure was reached. We believed there were some instrumentation problems and therefore scheduled a new test at Silver Jack about six months later.

The tests we had run on the previous occasion were repeated. However, this time the data was analyzed onsite. It showed similar results to the first test. This led us to suspect the air valve was not operating correctly. We installed a video camera in the gate chamber (since we could not send personnel in during the test) and attached several flags around the air valve which would indicate air movement. The test was repeated and our suspicions were proved out. The video showed almost no air movement into the valve. We entered the conduit after the appropriate safety clearances were in place and inspected the manifold which distributes air into the pipe from the air valve. We found a layer of fine sediment present in the manifold cavity which essentially plugged the air intake. In addition, a fair amount of rust was present, restricting the diameter of the intake holes, figure 4.

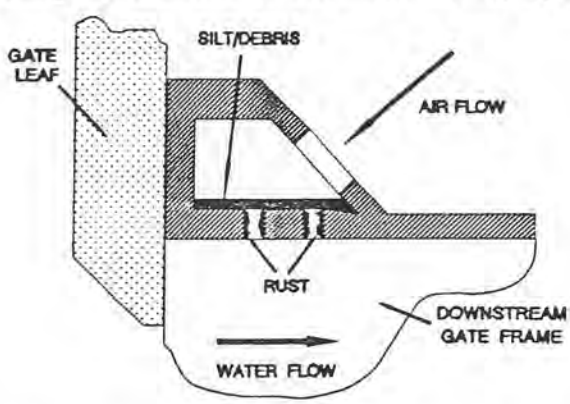

Figure 4.-Cross section of air manifold in top of downstream gate frame. Note clogging of the air passages.

We cleared the sediment and as much of the corrosion as possible and reran the tests. The air valve operated properly with a substantial increase in air flow. The conduit pressures, while still subatmospheric, were increased by about 4 lb/in^2.

The test procedure developed from the model study was also run. This called for opening the guard gate with fully unbalanced head to a 20-percent level and then closing it. We measured the total force (frictional, hydrostatic, and hydrodynamic) required to do this operation. Figure 5 shows this force diagram. Maximum load occurred below a 5-percent opening on the opening cycle.

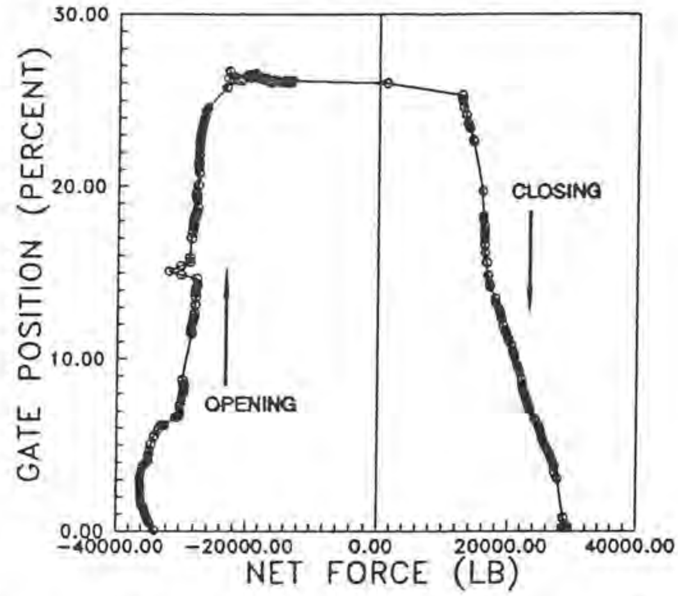

Figure 5.-Total force required to open and close the guard gate at Silver Jack Dam to a 20-percent level. Example of sample test procedure.

The results of these first field tests were extremely valuable in the development of the final test procedures. They showed us that even though a conduit appears to be protected by adequate air venting, an inspection of the air valve, piping, and distribution manifold should be completed regularly to ensure that they will operate properly. In addition, we suggested a design modification to the manifold in the downstream gate frame, opening up the many small diameter holes into one or two larger slots. This modification would allow for easier inspection and possibly would prevent the problem of plugging in the first place. These tests also indicated that the test procedures could be modified to only open the gate up to 10 percent, since the maximum hoist load occurred below this level. Because these tests were carried out on one of the newer gate leaf designs (45° gate lip and narrow seat) we decided to repeat our test procedures on one of the pre-1940's leaf designs prior to instituting the new procedures.

The Tieton Dam outlet works near Yakima, WA, featured guard gates of the pre-1940's design. This structure had two 5- by 6-foot guard gates that were located about 500 ft upstream from two 60-inch jet-flow gates. Two separate 72-inch steel pipes connect the guard gates to the regulating gates. We decided to perform a balanced head test, and then perform the unbalanced test according to our original test procedure (20-percent opening). Again, the hoist loads were monitored. Results showed that the maximum load occurred at a gate opening of about 5 percent, figure 6.

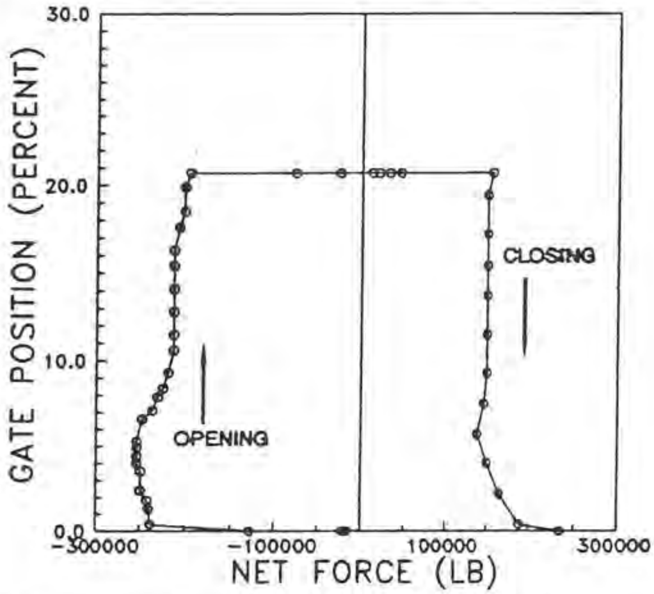

Figure 6.-Proposed guard gate emergency test procedures at Tieton Dam outlet works. Note maximum force occurs within the 0- to 10-percent open.

This test reinforced our previous findings that there was no need to open the guard gate to a 20-percent level and that 10 percent should be adequate to test the maximum hoist loading.

To some extent, we have avoided the question of testing the air valve capacity in the emergency situation. Reclamation takes the position that these tests are essentially needed to verify that the guard gate can be operated in an unbalanced head condition, which is what this test procedure verifies. However, in a fully unbalanced closure, there are still risks to the conduit downstream from the guard gate if the air valves do not operate properly. In general, this test procedure does not attempt to fully test the operation of the air valves, however as shown in the two field tests, the air valves will operate at a reduced capacity without exposing the conduit to a critical situation.

Summary

Reclamation has been involved in a 5-year program to develop a comprehensive test program for the emergency closure (unbalanced head) of high pressure slide gates which are not short coupled. This program has involved review of the pertinent literature, a scale hydraulic model study, and two field prototype investigations. As a result, Reclamation has instituted a field test procedure which is now being applied during scheduled Review of Operation and Maintenance examinations. The procedure calls for opening the guard gate to a 10-percent open position with fully unbalanced head conditions and then reclosing the gate. Safety precautions include analysis of the site prior to the test to ensure that the pipeline downstream from the guard gate is adequately protected by either its design strength or automatic air vents. In addition, an inspection of the air vent and manifold area is needed prior to the field test to ensure that they are not plugged. The unbalanced gate operation can then begin with the conduit downstream from the guard gate dewatered. The idea is not to subject these facilities to possibly destructive conditions just for a test. We feel that the main issue of the test is to show that the hoist capacity is adequate to open and close the gate under unbalanced head conditions. If this is satisfied, then in the case of a true emergency, the gate should operate as expected.

Since instituting this test program, we have identified the need to test additional gate types that are used occasionally as guard gates. The two types most prevelent in Reclamation dams in addition to the slide gate, are fixed wheel gates and ring follower gates. While the test procedure might be similar, it may need to be modified to reflect the differences in operating characteristics of individual gate types. Reclamation plans to study this problem further during the summer of 1993 by performing two field tests and possibly some additional laboratory work. Additional experiences under this program are described in papers listed under References.

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