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ABRASION/EROSION IN STILLING BASINS

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INTRODUCTION

Many stilling basins have experienced damage caused by rock, gravel, and sand brought into the basin by back flow over the stilling basin end sill. Normal operation of a hydraulic jump energy dissipation basin can cause a reverse flow eddy over the basin end sill and lower apron as shown in figure 1. This counter-rotating eddy is driven by a high velocity jet rising off the basin floor near the end of the basin. Riprap placed on the apron downstream of the basin end sill is typically designed to be stable under this condition. However, small material can be transported into the basin and trapped where turbulent flow continually moves the material about the surface, eroding the concrete. The cost for these repairs, in terms of time, effort and money, can be significant. If a means to reduce the reverse flow can be found, large savings can be obtained. One possible solution that is currently being studied at the Bureau of Reclamation's Water Resources Research Laboratory (WRRL) is to install flow deflectors in the basin to improve inter-basin flow conditions and minimize upstream velocities over the basin end sill (figure 2).

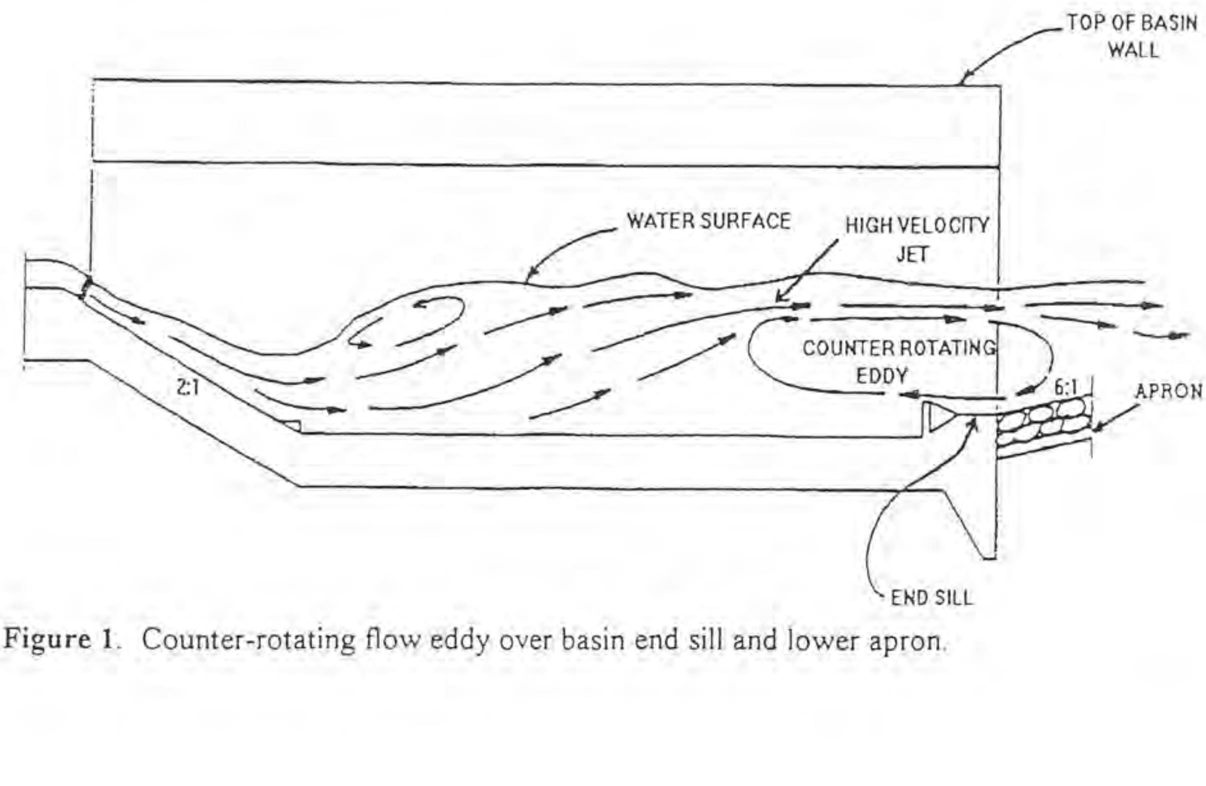

Figure 1. Counter-rotating flow eddy over basin end sill and lower apron.

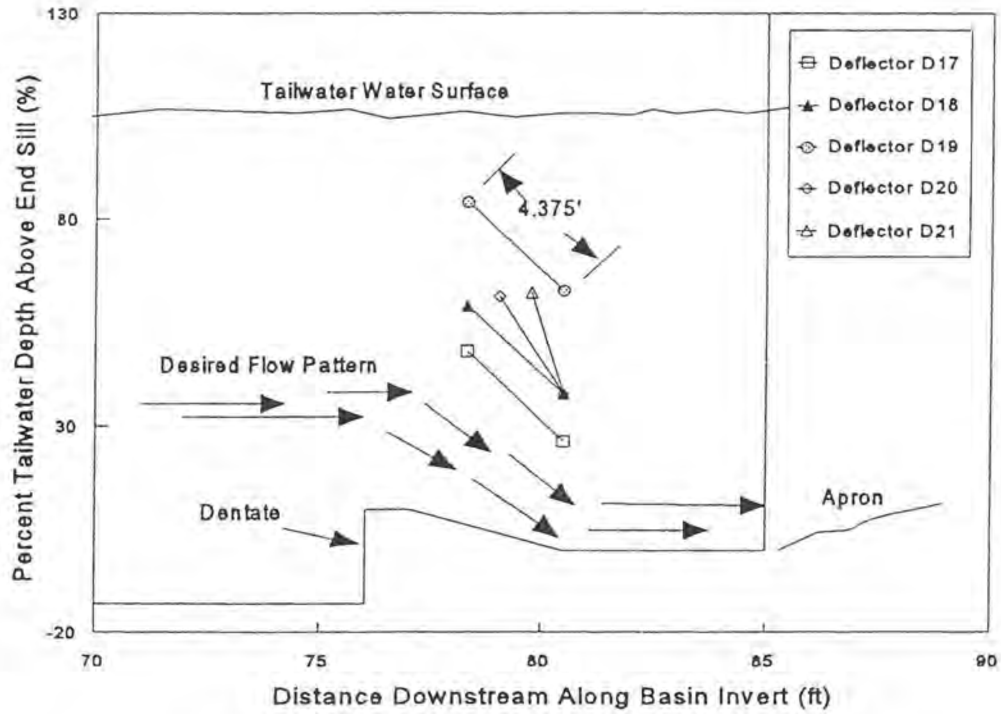

Figure 2. Deflector locations with respect to tailwater depth above the basin end sill

EXPERIENCES

Many stilling basins have experienced abrasion damage, as exemplified below at several Reclamation Dams. Often abrasion has progressed to depths exposing reinforcement and requiring repair of concrete by sawcutting, sandblasting, and concrete replacement with polymer concrete, or silica fume concrete.

Vallecito Dam - Vallecito Dam, completed in 1941, experienced abrasion/erosion damage in the outlet works stilling basin in the 1980's. The repairs involved a silica fume concrete with high slump and 9000 lbs/in^2 strengths. The work was completed in 1991. The spillway chute has since experienced more erosion indicating this is a continuing problem.

Ridgway Dam - An underwater inspection of the Ridgway Dam outlet works stilling basin revealed that the concrete floor was severely eroded, with the reinforcing bars exposed. The region will have this work repaired using a two phase process. The first phase is to construct bypass capacity to dewater the stilling basin, remove all materials, and determine the extent of repairs needed. The second phase the following year will be to make the repairs. The work scope is not determined but when all is complete the cost may be between $200,000 and $1,000,000.

Taylor Draw Dam - In 1991, about $200,000 was spent to repair abrasion damage to the Taylor Draw Dam outlet works stilling basin. After just one operating season, an inspection revealed that abrasion damage had again occurred. After repairs were complete the second time, a study conducted by WRRL demonstrated that the installation of flow deflectors improved the basin's flow distribution significantly, greatly reducing the potential for movement of material into the basin. The deflectors have been in place for 4 years with no further repairs to the basin concrete required.

THE MODEL

A physical model is being used to investigate hydraulic conditions in Type II stilling basins and to study the affect of deflector positioning and inclination on flow patterns over the basin end sill. The study will be used to optimize and generalize flow deflector designs based on basin geometry and operating conditions. The Ridgway Dam outlet works and its Type II twin bay stilling basin are being used for the model investigations. The model includes the 42-in high pressure slide gates discharging into 2:1 sloping chutes and 12 ft wide bays. The basin is 85 ft long. Froude scaling was used to model the outlet works at a 1:10.5 scale. The downstream riprap apron topography was modeled on a 6:1 slope with moveable bed material to simulate the abrasion source. Unit discharges (q) (corresponding to 40-, 60-, 80-, and 100-percent gate openings for the Ridgway Dam outlet works), and percent of tailwater depth were used to describe flow conditions. Velocity measurements were determined using a sontek acoustic flow meter and were measured at the downstream end of the basin end sill in the center of the bay. Bottom velocities were measured 5.25-in above the basin end sill. All velocities are described in terms of average velocities. Tailwater was set according to the tailwater curve generated for the Ridgway Dam outlet works operations.

INVESTIGATIONS

Flow conditions over the basin end sill were characterized with profiles representing average velocities (negative values represent velocities in the upstream direction) mapped along the vertical axis in the center of the bay for unit discharges of 29 $ft^3/s/ft$ (40% gate), 41 $ft^3/s/ft$ (60% gate), 52 $ft^3/s/ft$ (80% gate), and 60 $ft^3/s/ft$ (100% gate) as shown in figure 3. The vertical axis shows the relative depth in percent of total tailwater depth over the basin end sill. Initial investigations determined that the most effective position along the length of the basin was to locate the deflector directly above the downstream slope of the basin dentates. Once this was established, the most effective position along the vertical axis was investigated. Figure 3 shows that as values of unit q increase, the thickness of the high velocity (downstream) jet increases, thereby lowering the transition point between upstream and downstream velocities above the basin end sill. The effectiveness of the flow deflector is dependent on the vertical location of the deflector with respect to this transition point and its ability to trap and redirect a large enough portion of the high velocity jet (immediately above the transition point) to improve flow conditions. With this in mind, three vertical locations and several deflector angles were investigated.

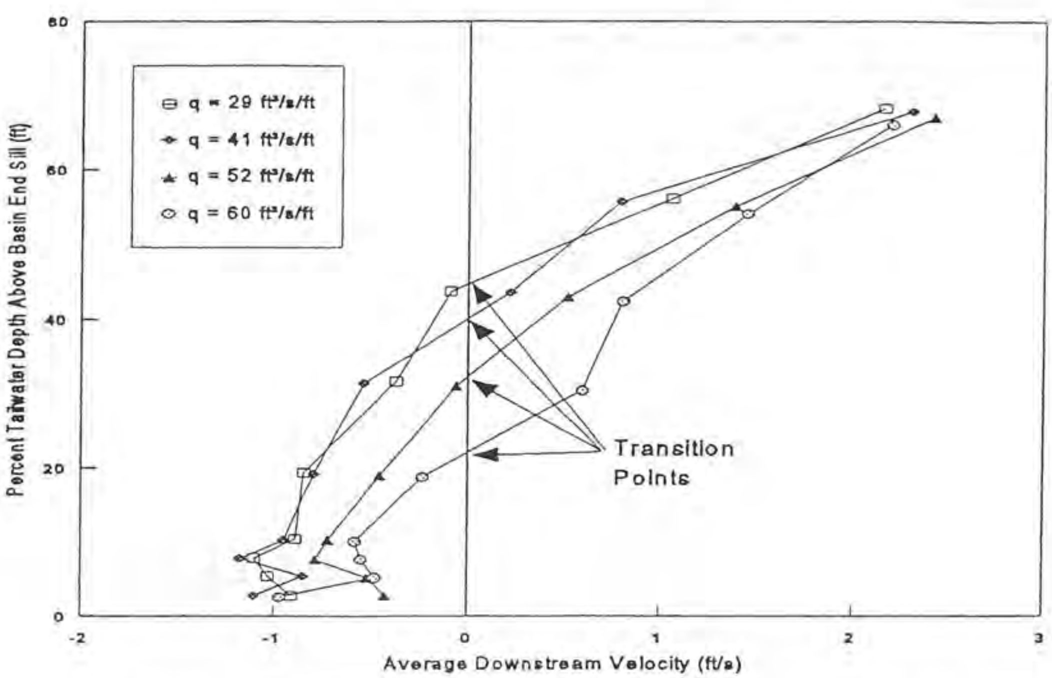

Figure 3. Velocity profiles measured along the vertical axis above the basin end sill.

All of the deflectors tested were 4.375 ft deep and were located as shown in figure 2. Deflectors D17 through D19 were positioned at an angle of 60 degrees, and deflectors D20 and D21 were positioned at 70 and 80 degrees, respectively.

Figure 4 shows bottom velocities measured near the basin end sill for deflector positions D17 through D21 for each flow tested. The results of these investigations show that the performance of each deflector varies over the range of flows. When the deflector was positioned low in the basin and just above the transition points of the higher flows (i.e. D17) the deflector performed well at the high flows. However, it became ineffective as the flow was decreased because the transition point moved above the location of the deflector. As a result, at the lower flows, the deflector missed a major portion of the high velocity jet because it was positioned below it. A similar problem occurred when the deflector was positioned too high (i.e. D19). Although the deflector was in good position (just above the transition point) to redirect the jet at the lower flows; as the flow was increased, the transition point moved too far below the deflector for it to remain effective The solution was to position the deflector (D18) between the locations of deflectors D17 and D19 where it would be less sensitive to the movement of the transition point. This produced positive downstream velocities (average) throughout the range of flows.

Next the angle of the deflector was varied. Deflectors D20 and D21 were installed at the same location as D18 except with the angle increased to 70 and 80 degrees respectively.

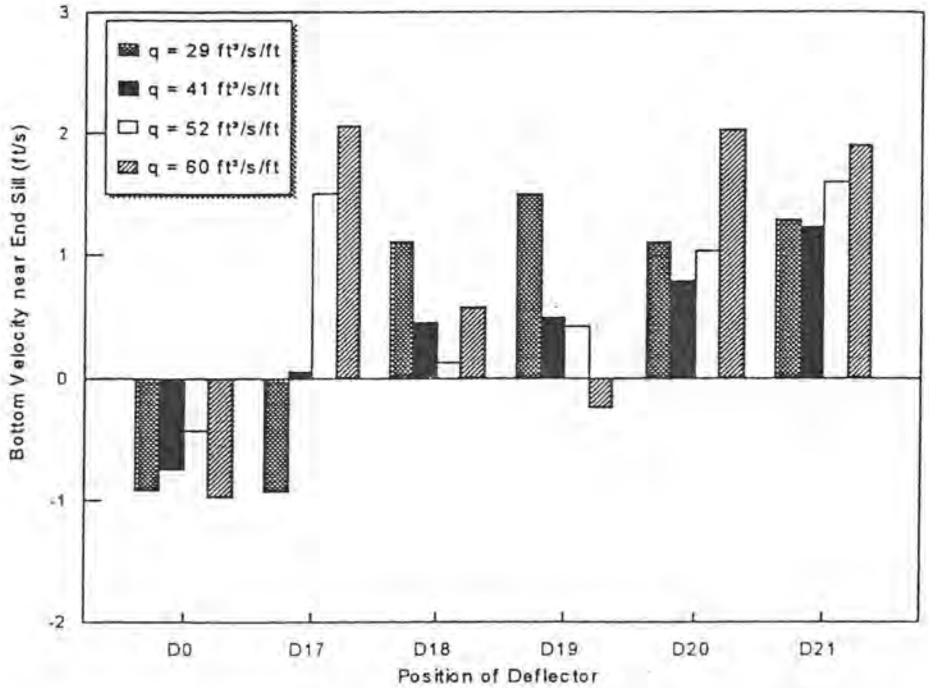

Figure 4. Bottom velocities (average) measured for each deflector position. (D0 indicates no deflector was installed.)

Figure 4 demonstrates that flow conditions were improved as the angle was increased and the best overall results, throughout the range of flows, occurred with deflector D21 installed.

Table 1 shows the velocity range within one standard deviation (67 percent confidence level) for the bottom velocities measured for deflector D21 and with no deflector (D0) installed. The table demonstrates that with deflector D21 installed, velocities over the basin end sill act predominately in the positive or downstream direction. Without a deflector, the velocities predominantly act in the upstream direction.

Table 1. Bottom velocities within one standard deviation.

Deflector Position	Velocity Range Within One Standard Deviation (ft/s)			
	$q = 29$ ft^3/s/ft	$q = 41$ ft^3/s/ft	$q = 52$ ft^3/s/ft	$q = 60$ ft^3/s/ft
D21	-.14 to 2.67	-.08 to 2.56	.05 to 3.13	.14 to 3.62
D0	-2.1 to .239	-2.22 to .02	-1.62 to .43	-1.7 to .51

Each of these investigations was conducted with the tailwater depth set at a specific level according to the tailwater curve for Ridgway Dam outlets works operations. Future investigations will determine the best deflector positioning relative to fluctuations in tailwater depth.

CONCLUSIONS

Deflectors have been designed and installed at Taylor Draw Dam with marked improvements in stilling basin flow patterns; and based on the model study, performance of the deflectors show the potential for significant savings by reducing damage caused by abrasion.

The results of the Ridgway Dam hydraulic model study indicate that the effectiveness of the deflector depends on the basin discharge and on the deflector's relative position and sensitivity to the movement of the transition point throughout the range of operations. The study showed the deflector was most effective when it was located between 38 percent and 69 percent of the average tailwater depth over the full operating range, and positioned at an angle of 80 degrees.

Further investigations will determine if the deflector location can be generalized over large ranges of tailwater depth. If the variation of the tailwater (i.e. the operating range) is greater than 200 percent, a single deflector may not be effective. The structural design of the deflectors will depend on the material used, the overall width of the stilling basin, and the angle of the deflector. Future work may also involve determining the maximum basin width that the deflector design will be effective.

Further work at the Bureau of Reclamation Water Resources Research Laboratories will include generalizing flow deflector designs for Type III stilling basins.

REFERENCES

[1] Dodge, Russ, "Hydraulic Study of Taylor Draw Dam Outlet Works," U.S. Department of the Interior, Bureau of Reclamation Report R-92-10, March 1992.