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Hydraulic Model Study of the River Return Terminal Structure, South Fork Tolt River Project

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for the City of Seattle

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Introduction

The Water Resources Research Laboratory of the Bureau of Reclamation was requested by the City of Seattle to perform a hydraulic model study of the terminal structure of the South Fork Tolt River Project. This structure delivers water in excess of the City of Seattle's water supply needs back into the South Fork Tolt River. The terminal structure will be used for both flow control and energy dissipation. An additional feature of the design is that it serve as a barrier to exclude fish from entering the structure where they might become trapped or injured.

The Bureau of Reclamation's Water Resources Research Laboratory (WRRL) constructed and tested a 1:6 Froude-based scale model of the terminal structure to aid in the design. The concept studied used a 48-inch Monovar valve for flow control. The valve discharged freely into a hooded chamber with the flow passing from this chamber into a weir box. After passing over a 9.14 m (30 ft) long weir, the flow dropped onto an apron and then flowed back into the river. The basic plan for the terminal structure is shown in figure 1.

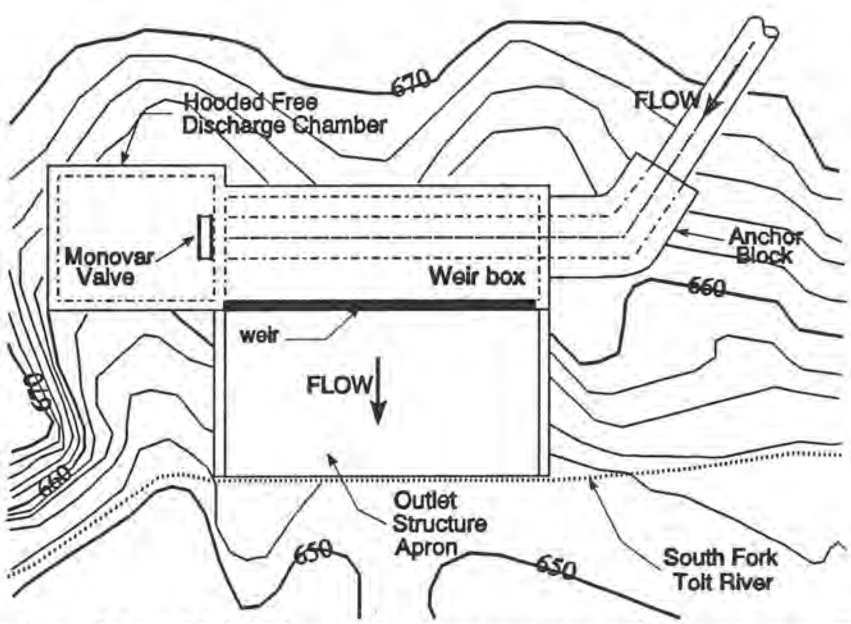

Figure 1: Plan view of the initial design of the river return terminal structure. Free discharging Monovar valve.

Experience with this type of structure is limited. The use of the Monovar valve, discharging freely into a confined chamber has not been well documented and presented some unknown design characteristics which were important to the overall performance of the structure. Tests concerning the discharge capacity and flow coefficients of a freely discharging Monovar have been completed; however, certain characteristics, particularly energy dissipation and aeration have not received much attention. The prototype installations of the Monovar in end-of-line applications have generally had the valve discharging into a plunge pool or stilling basin.

The main goal of the model study was to observe the operational characteristics of the valve/chamber combination, in particular the energy dissipation and optimize the conditions where possible. In addition, the resulting flow on the apron must provide an effective fish barrier. This type of fish barrier has been well documented (see the Trinity and Feather Rivers in California, the Carmen-Smith Project on the McKenzie River and the Fall Creek Dam in Oregon). The original design goal was to keep a shallow depth on the apron (about 6-inches), with a minimum apron velocity of 16 ft/s. The flow depths should also be relatively uniform over the width of the apron.

Methods and Materials

The hydraulic model was designed using Froude similarity,

$$\frac{V_m}{\sqrt{g_m L_m}} = \frac{V_p}{\sqrt{g_p L_p}}$$

where m and p indicate model and prototype respectively. Generally when modeling free-surface turbulent flows, Froude similarity is chosen since the gravitational or inertial forces are much larger than the viscous forces. The model scale was chosen based on the availability of an 203.2 mm (8 inch) Monovar valve which had been tested in the WRRL as part of our research program (WATER Project NM003, *Improved Design of Gates and Valves*). Using this valve led to a geometric length scale of 6, with corresponding velocity and discharge ratios of 2.45 and 88.18 respectively. These ratios describe the operating condition in the model to simulate prototype design conditions.

The model was constructed in the WRRL and used the laboratory system to provide flow and flow measurement. Figure 2 shows the extents of the model. Additional views of the model

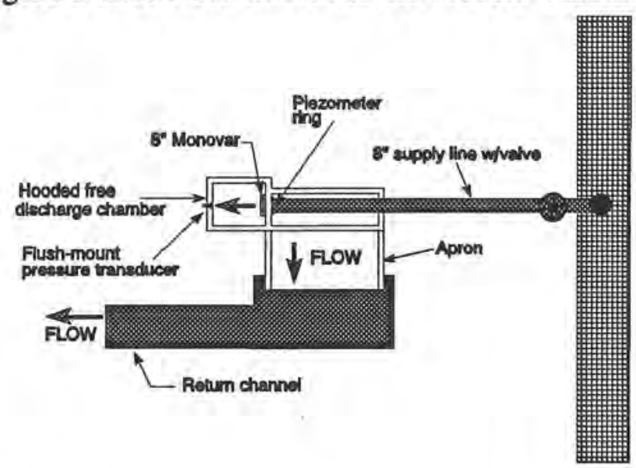

Figure 2: Extents of 1:6 scale laboratory model.

with model dimensions are shown in figure 3.

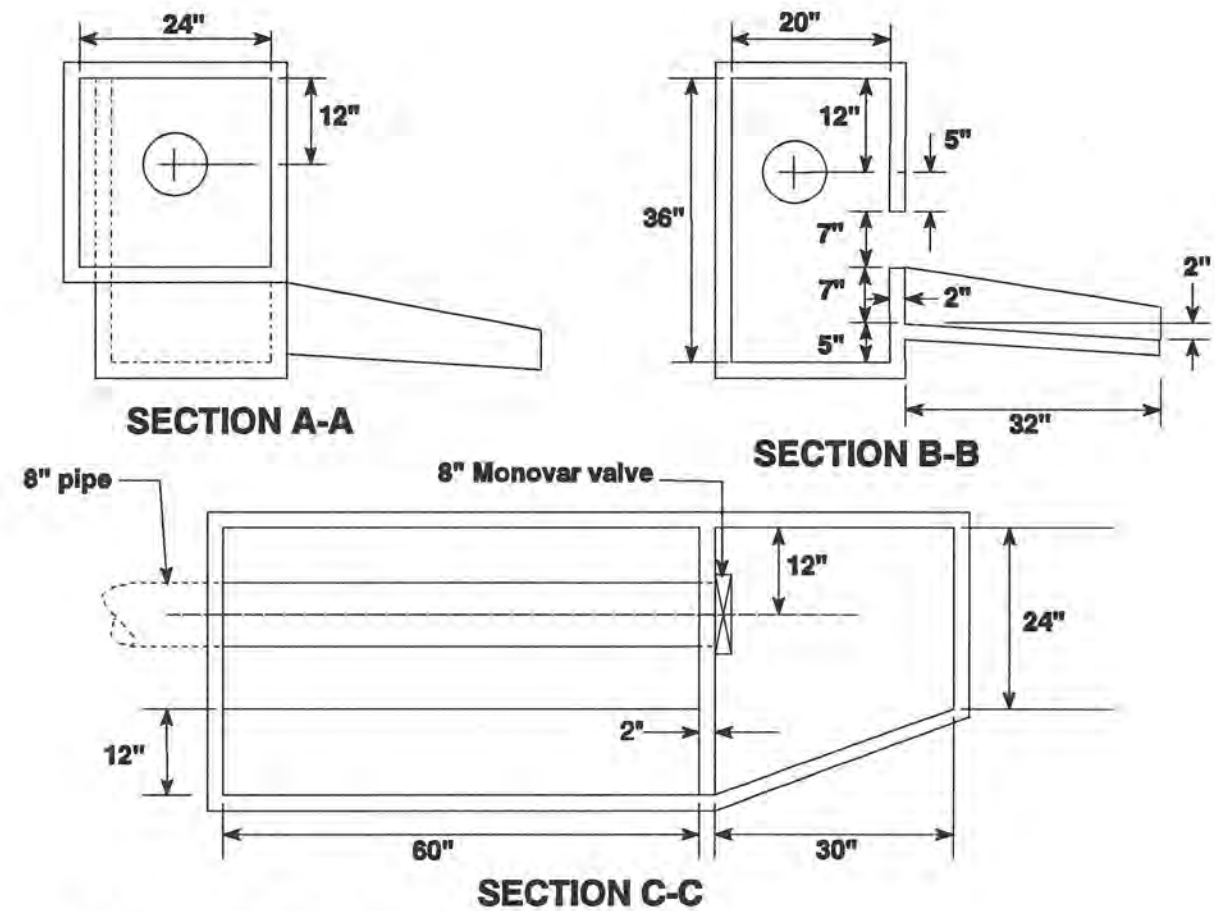

Figure 3: Sectional view of the terminal structure model.

Pressure head at the valve was measured with an electronic pressure transducer attached to a piezometer ring directly upstream from the valve. Both the control valve entering the model and the Monovar opening were adjusted to duplicate design discharge and head conditions. Flow from the valve was observed through a plexiglas side wall in the hooded chamber. Impact pressures were measured on the end wall of the chamber using flush-mounted pressure transducers. Flow depths on the apron were measured with both mechanical point gages and an ultrasonic level sensor. Flow conditions were also recorded on video tape.

Results

Discharge characteristics of a freely discharging (atmospheric conditions) Monovar were taken from previous tests performed at the WRRL on an 8-inch Monovar valve. The valve was tested on Reclamations' high-head pump facility and discharges were measured over a range of openings for heads up to 300 ft.

The data are presented in figure 4, using the same flow coefficient which Monovar presents in their literature. C_v is defined as:

$$C_v = \frac{Q}{\sqrt{\Delta p}}$$

where: Q is discharge in gal/m and Δp is pressure drop in lb/in^2

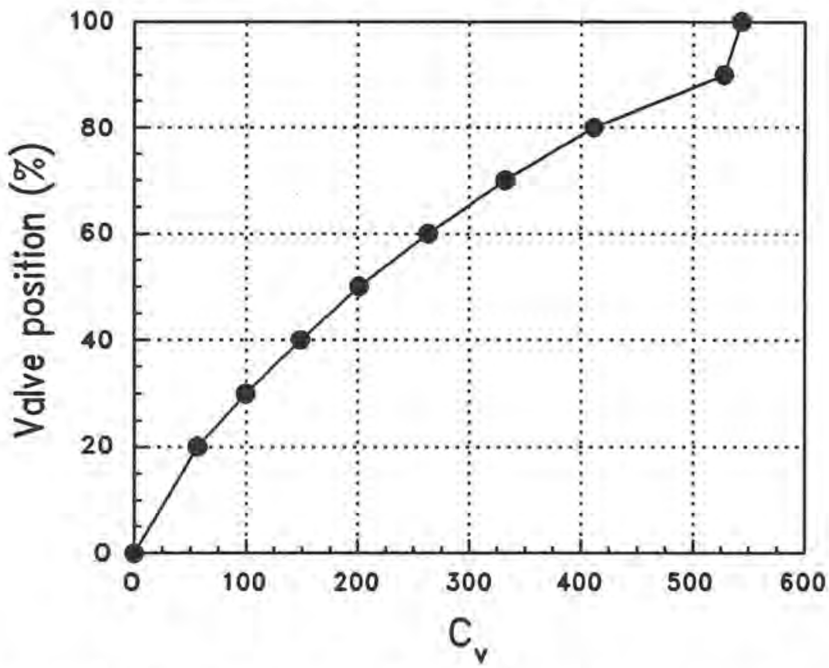

Figure 4: WRRL test data for a freely discharging 8-inch Monovar valve.

The original design configuration was initially tested to observe the characteristics of the hooded chamber, the flow in the headbox of the weir, flow over the weir and finally flow on the apron. We first looked at a series of flowrates, 50, 150, and 245 ft^3/s. For all but the smallest flow, the conditions over the weir and on the apron were very uneven. Flow from the valve into the chamber appeared much as was expected. The individual jets from the Monovar caused a highly aerated flow condition in the chamber. The entrained air bubbles tended to rise to the free surface in the weir box as the flow exited the valve chamber. This causes upwelling, resulting in a highly turbulent and uneven water surface in the weir box. In turn, the flow on the apron also was unacceptably uneven.

The first modification was to decrease the size of the opening from the valve chamber into the weir box. The height of the entrance was dropped 2 ft, blocking 20 ft^2. While this did slightly improve the flow distribution over the weir, the resulting apron flow was still uneven. It appeared that the only way to achieve the desired flow conditions on the weir and apron would be to add some type of internal vanes or baffles to the weir box. In addition to the problems caused by large amounts of air coming out of solution at the entrance to the weir box, the narrow width of the weir box forces the flow to turn 90-degrees in a very short distance before passing over the weir. A baffle, similar to a wave suppressor was installed about 2 ft upstream from the weir crest, figure 5. The addition of the baffle caused a fairly large component of velocity coming around the bottom of the wave suppressor, resulting in an upward angle to the flow over the weir. With the wave suppressor still in place, the area of the opening was reduced so that all the flow from the dissipation chamber entered the weir box behind the wave suppressor. The main result of this modification was an increase in the velocity of the flow entering the weir box, making the wave suppressor less effective.

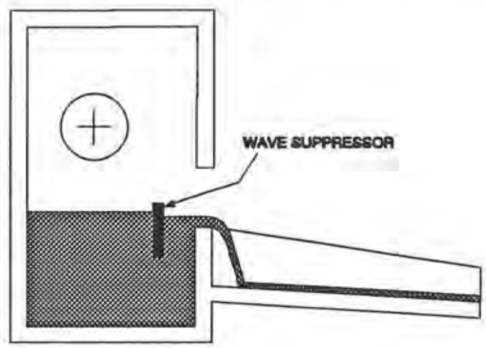

Figure 5: Wave suppressor-type baffle.

The next series of modifications involved a series of vertical posts placed parallel to the weir crest in a similar location as the wave suppressor, figure 6. These posts were sized to be 6-inch-by-6-inch in the prototype. While the posts did aid in turning the flow prior to passing over the weir crest, there was still substantial runup at the far end of the weir box from the dissipation chamber. Uneven flows over the weir crest and in the chute still remained. The final modification and recommended design was to orient the posts in a diagonal across the weir box, figure 6. The open area of the post baffle was 60-percent with a graduated opening between posts going from larger to smaller across the width of the weir box. This arrangement had a much improved visual appearance, especially at the 165 ft^3/s discharge with an average flow depth across the weir of 1.81 ± 0.09 ft. The performance at 245 ft^3/s was not quite as good, with an average flow depth of 2.33 ± 0.31 ft.

Impacts and energy dissipation characteristics of the discharge chamber were evaluated through visual observations and measurement of impact pressures on the wall opposite the Monovar valve. The 57 individual jets exiting the Monovar impacted the wall in a fairly tight circular pattern. The maximum pressures measured were 22.3 ± 1.4 ft of water above atmospheric conditions at a flowrate of 245 ft^3/s. The flow conditions inside the dissipation chamber were highly turbulent and very aerated. The valve did not become submerged for any of the discharges tested.

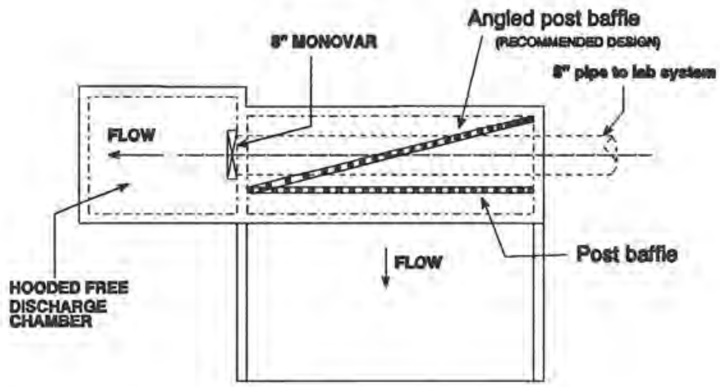

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Figure 6: Post baffles, parallel to weir and diagonal.

Discussion

The design of the terminal structure is quite unique. There has been some use of the Monovar valve discharging into confined chambers; however, none quite like this application. Considerable energy dissipation takes place in the discharge of this valve and the consequent mixing in the dissipation chamber. Reclamation's test program on the Monovar valve has found it to operate very well as a freely discharging valve. The main problems with this structure were in meeting the criteria for a fish barrier. To act as a fish barrier for salmonids, the flow on the apron should be of uniform depth across the entire apron width and no deeper than 6-inches. Most of the problems with flow distribution which were addressed in this study could have easily been solved with a larger weir box (longer and wider). However due to the site constraints, the only acceptable operation was achieved by placing vertical posts in a diagonal pattern across the length of the weir box. This arrangement appears to operate satisfactorily throughout the range of flows and should provide an effective fish barrier as prescribed by current practices.

References

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