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Flow Dynamics in a Typical Offset Joint on a High Velocity Chute Spillway

By

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INTRODUCTION

A 4-by-4 inch water tunnel was used to simulate the flow dynamics over an offset joint in a high velocity spillway chute. Water velocities up to 55 ft/s were tested. A transverse joint with gaps of 1/8-inch, ¼-inch, and ½-inch mm and offsets into the flow of 1/8-inch, ¼-inch, ½-inch, and ¾-inch in all combinations were tested over a range of velocities. Mean differential pressure across the downstream portion of the test section was measured with a Sensotec pressure transducer and an IOTech Wavebook data acquisition system. The cavity beneath the slab could be sealed or vented to the atmosphere to allow water to flow through the gap in the joint. Sharp edged, radius edged, and chamfer edged joints were modeled.

Flow details in the test section, including flow through the gap into the area beneath the slab were captured with a Dantec 2D PIV system. Two different joint/crack configurations were investigated including1/2-inch chamfered offsets for the 1/8-inch and 1/2-inch gaps during vented and sealed cavity operation. Free-stream test velocities of 20 ft/s and 30 ft/s were selected for each configuration.

Successive image pairs of the laser-illuminated flow field obtained during testing were processed (cross correlation) to obtain the velocity vector fields. The scale factors obtained from the camera setup were 8.020 and 8.231 pixels/mm for the 1/2-in and 1/8-in gap configurations, respectively. External seeding was not required since existing particulates in the laboratory supply system provided decent tracer particle image quality. The time difference between image pairs was set at 50 μs, the value observed to produce the best cross-correlation results, based on preliminary PIV setup testing over a range of □t between 25-150 μs.

The cross correlation process involved 16-pixel by 16-pixel interrogation windows with 50% vertical and horizontal overlapping, Gaussian windowing, and a No DC filter function. Masking of no-flow zones in the images field of view was implemented prior to image processing. Figure 1 shows a typical masked image obtained during testing. It was not possible to obtain velocity vector data in the cavity below the slabs since laser-sheet illumination of the flow field was imparted through the slotted window in the top the test section.

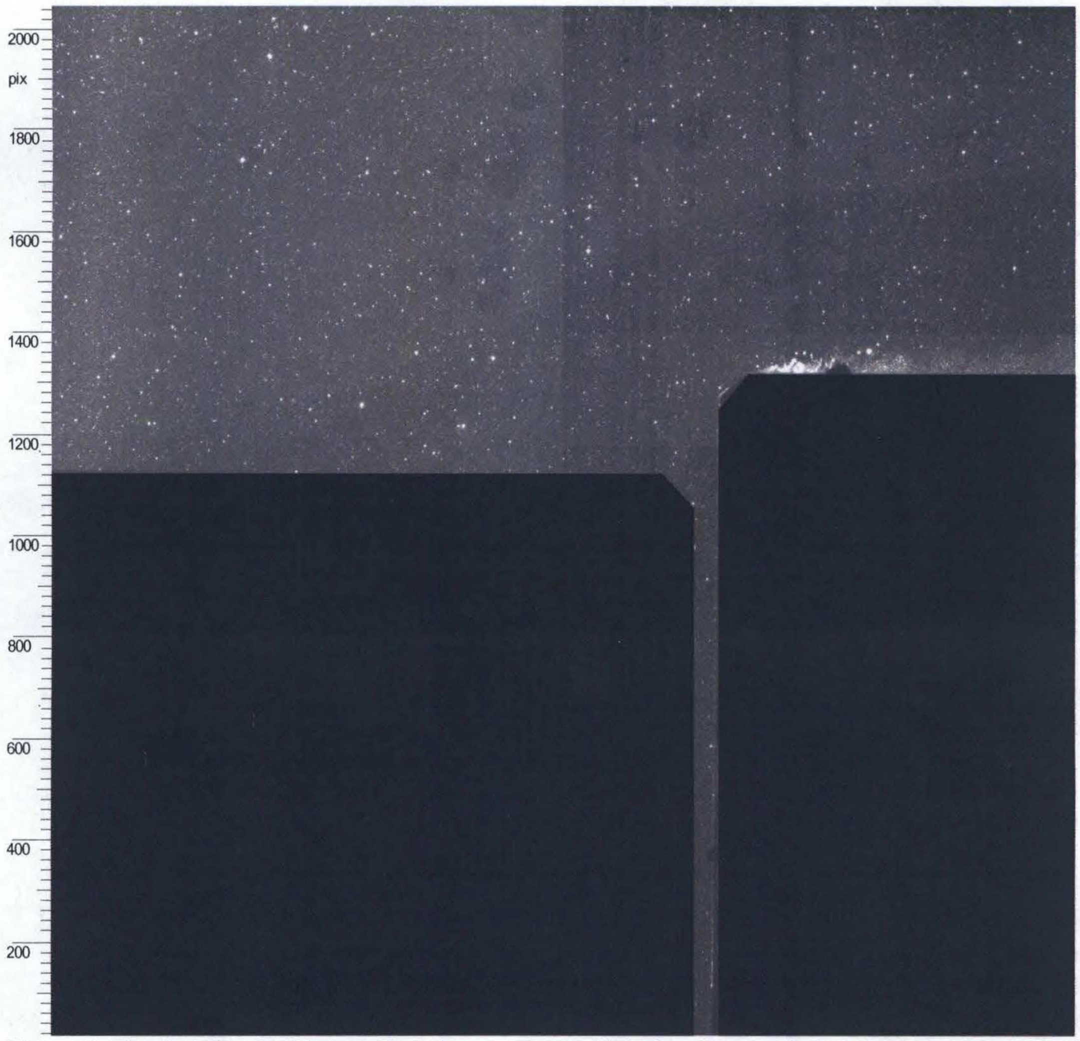


Figure 1: Typical masked image showing tracer particle density and joint/crack configuration for the 1/2-inch offset with 1/8-inch gap (flow is left to right).

The data processing chain can be summarized as follows: Masked image pairs □ cross correlation □ raw vector field □ moving average validation □ results vector field □ Tecplot data loader □ vector field plots and velocity profile plots. The *moving average validation* algorithm compares three neighboring vectors from the raw vector field plot. If any vector was found to deviate by more than 10% of the average of the three vectors, that vector was replaced by the average. Figure 2 shows a typical resulting vector field plot following validation. The green vectors represent those that were replaced during the validation process.

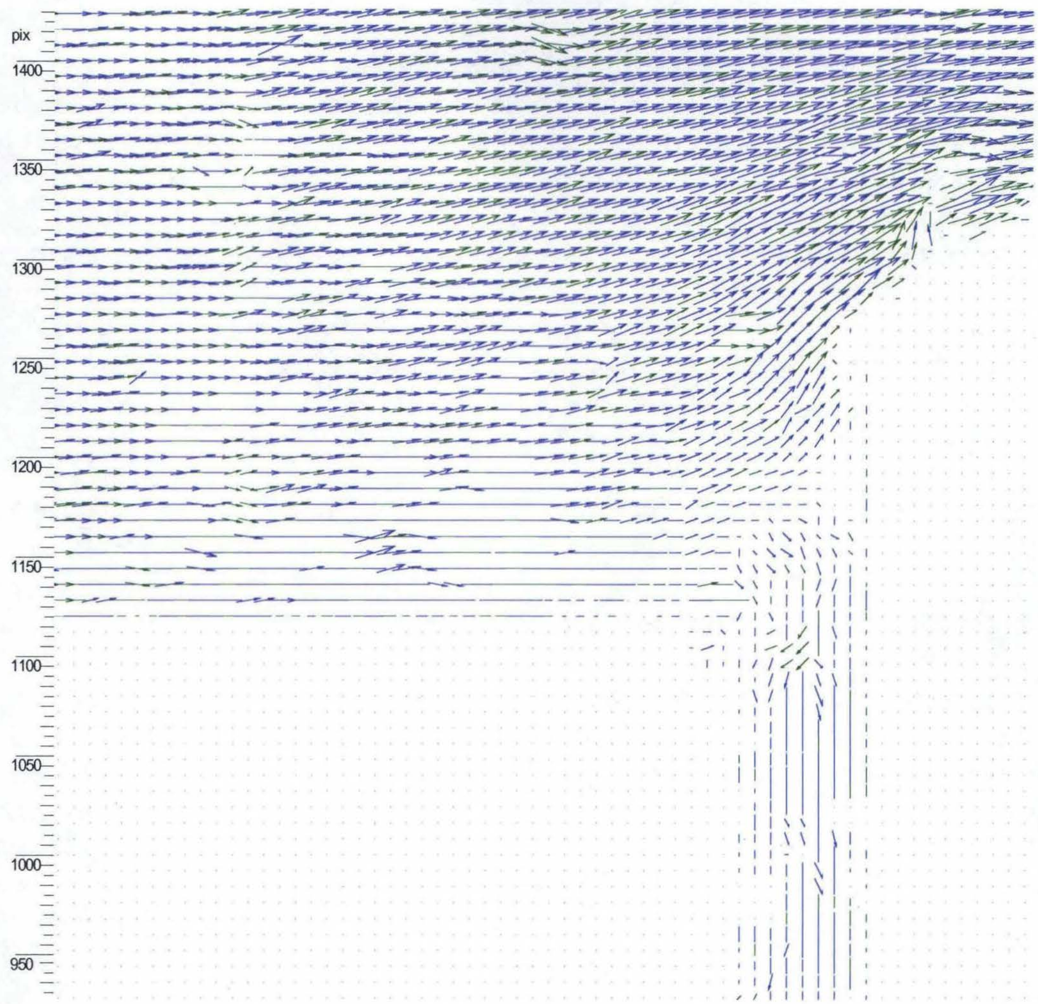


Figure 2: Typical vector field results following cross-correlation of the masked image pairs and moving average validation for the 1/2-inch offset with 1/8-inch gap. The green vectors were replaced during the validation process.

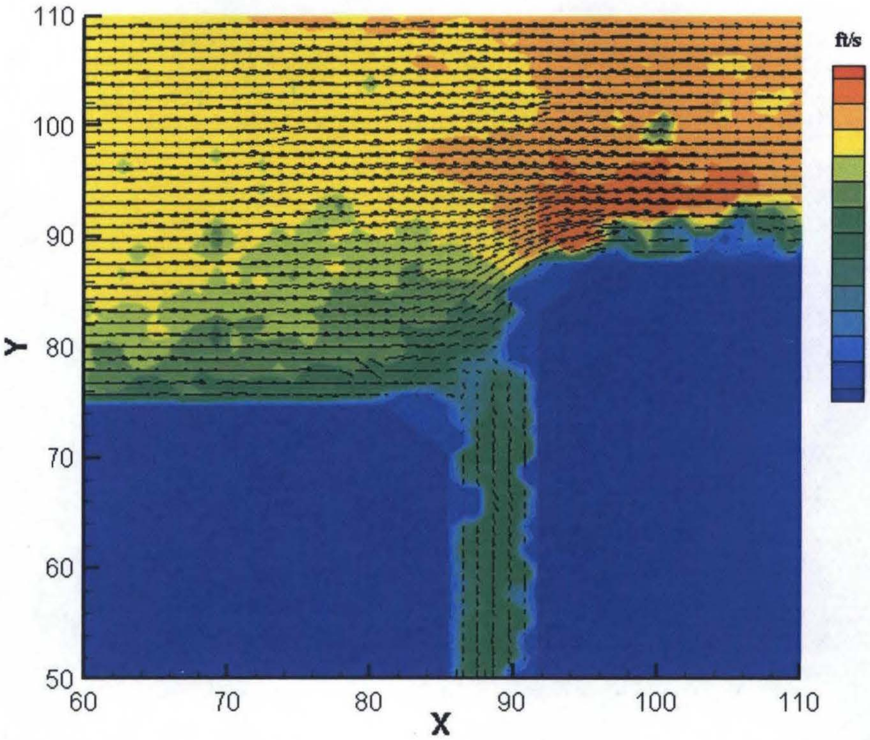
RESULTS AND DISCUSSION

In general, the results show the effects of gap, venting, and free stream velocity on the flow patterns in the vicinity of the joint/crack and offset for the range of configurations and operating conditions tested. The general effects of venting for all cases tested include: 1.) A slight change in the general extent of the stagnation zone near the upstream face of the offset as venting tends to increase the extent in comparison with sealed cavity operation; 2.) Alteration of the stream lines for the flow passing above the crack as venting tends to reduce the streamline displacement as compared with sealed cavity operation; and 3.) Increased vertical velocities into the joint/crack due to flow into the vent cavity during vented operation. However, the 1/2-inch gap exhibits greater sensitivity to venting in comparison with the 1/8-inch gap (figure 3). This is primarily due to the establishment of a dominant recirculation zone just downstream and below the trailing edge of the upstream slab for the 1/2-inch gap which is observed for both 20- and

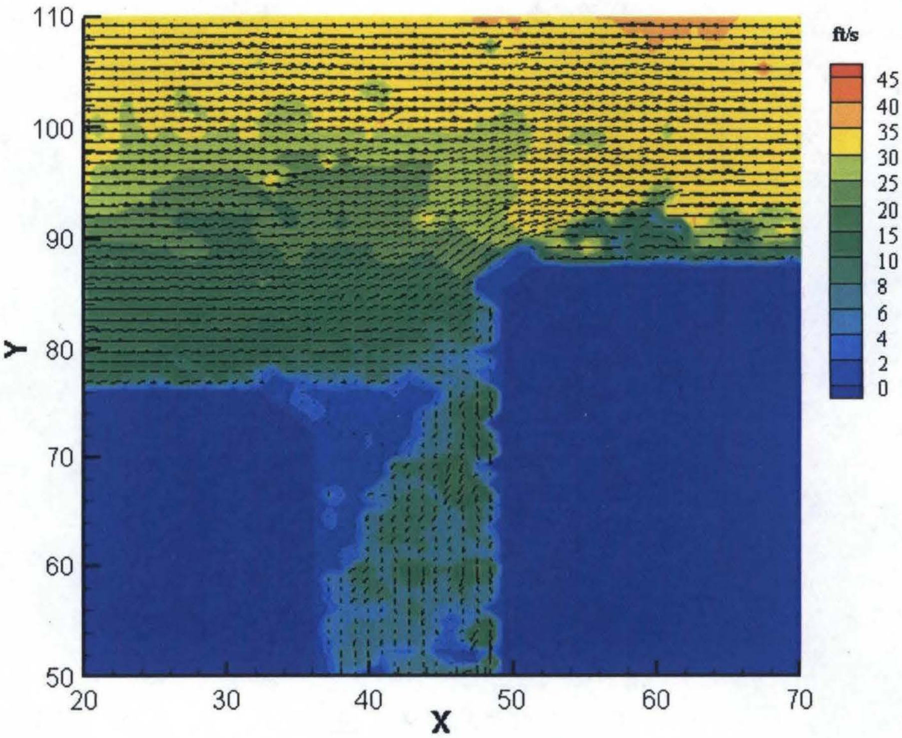
30-ft/s free stream velocities. Such recirculation is not evident for the 1/8-inch gap configuration under these test conditions.
The most interesting feature of the recirculation zone for the 1/2-inch gap involves the *effective width* through which dominant vertical velocities are observed. This *effective width* appears to decrease slightly with increased free-stream velocity. Such a result is physically reasonable in consideration of increased changes in momentum necessary to turn the flow vertically downward for increased free-stream when the possibility for recirculation zone exists. In this regard it appears that a smaller joint/crack gap is more conducive (at least along the test section centerline and for the free-stream velocities tested) to producing flow through the joint/crack during vented operation because it eliminates or at least limits the extent of recirculation. However, this physical explanation is complicated by the drive pressure presumably transmitted by stagnating flow along the offset face.

The recirculation zone effect is most evident in figure 4, showing the horizontal velocity profiles extracted form the PIV results for vented operation (*i.e.*, velocity profiles are along the centerline of the test section). For the 1/8-inch gap, a significant difference in velocity profiles exists in comparison of the 20- and 30-ft/s free-stream velocities; the latter producing larger velocities and hence unit discharges. Such results are not observed for the 1/2-inch gap in which case the gap velocity profiles are nearly independent of free-stream velocity. These results have interesting and important implications for unit discharge, indicating that for smaller gaps, increased free-stream velocities are expected to produce increased joint/crack unit discharges. However, as the gap increases there is less sensitivity to unit discharge with free-stream velocity for the range of conditions tested (*i.e.*, 20- and 30-ft/s). In fact, volumetric flow rate measurements of joint/crack discharges indicate that higher free stream velocities actually produce lower joint/crack unit discharges. Again, such results are physically reasonable owing to the observed recirculation zone for the 1/2-inch gap configuration and increased changes in momentum required for increased free-stream velocities. Though there is expected to be a joint/crack size limit under conditions where the joint/crack internal flow resistance begins to control the flow rate following the establishment of smooth streamlines entering the joint/crack.

With regard to uplift pressure specifically, it is less evident how these reported velocity field characteristics directly affect pressure distributions on the upper and lower surfaces of the downstream slab. In comparison of vented and sealed cavity operations, slight increases in velocity are observed just downstream of the offset slab leading edge. However, there is little evidence of changes in the extent of the separation zones even though larger separation zones are expected for larger free-stream velocities. Thus, from a qualitative perspective, it can only be interpreted that the increases in free-stream velocity downstream of the joint/crack are likely to decrease static pressures along the top surface of offset slab. This combined with stagnation at the leading edge (offset face) resulting in large pressures transmitted to the cavity below the slab has the potential to increase uplift pressures for sealed cavity operation in comparison with vented conditions.

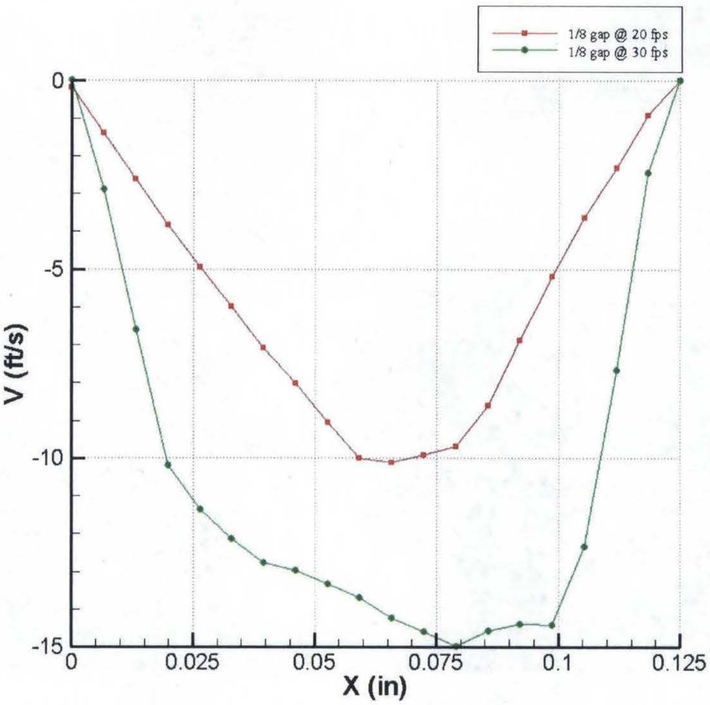


1/8-inch gap, 1/8-inch offset, flow in crack, V_m=30 ft/s

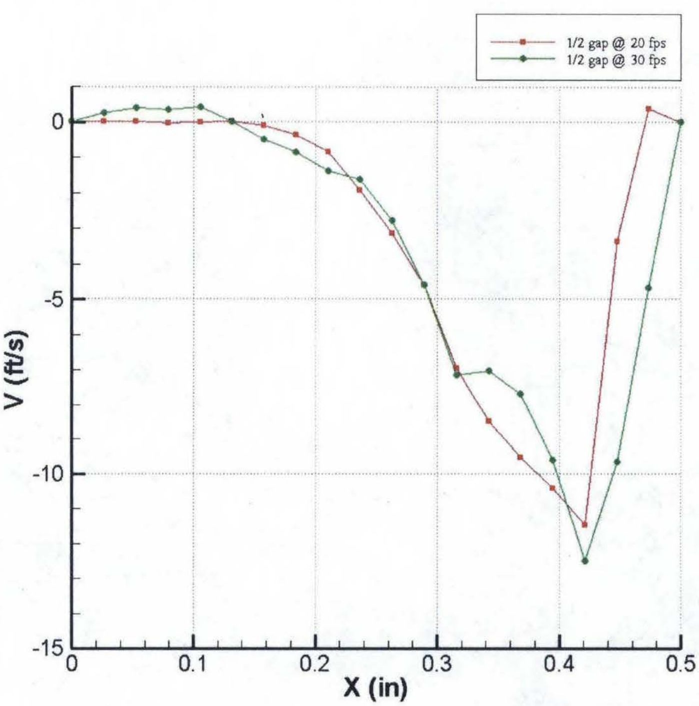


½-inch gap, 1/8-inch offset, flow in crack, V_m=30 ft/s

Figure 3: Mean velocity of 30 ft/s over open offset joint. 1/8-inch and 1/2-inch gap with 1/8-inch offsets.



1/8-inch gap width (note dependence on freestream velocity



½-inch gap width (appears independent of freestream velocity)
also a much less efficient path to transfer water through the crack, note location of recirculation zone along the leading edge of the cavity.

Figure 4: Velocity profiles across the gap widths, extracted from the PIV data for freestream velocities of 20 and 30 ft/s.

Attachment 1

TSC SECURITY REVIEW OF PROPOSED PUBLIC DISCLOSURE OF TECHNICAL INFORMATION

Type: Abstract: ✓ Publication: _____ Presentation: ✓ Other: _____

Title: Flow Dynamics in a Typical Offset Joint on a High Velocity Chute Spillway

Brief Description of Information: Flow dynamics over an offset joint in a spillway

Requesting/Sponsoring Organization: ASCE

Forum and Date (if Presentation/Publication): Hyd + Measurements + Exp Methods 9/10-13/2007

Project/Feature: Reclamation wide - no facilities listed

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