Quarterly Progress Report

Oct. 1, 2011 to Dec. 31, 2011

Previous stage mainly included the bed characterization as well as the 2nd Corrugated Metal Pipe (CFD) preparation. The upcoming stages would involve elevated gravel bed that would simulate sediment in the culvert. In order to better understand the effect from roughness of the gravel bed as well as to support CFD study, testing that used the bare flume without corrugated pipes were conducted. A two-phase experiment with the discharge of the 0.0205 m^3/sec and water elevation of 0.195 m under steady uniform flow condition was conducted for both smooth bed flume (without gravel) and rough bed (with gravel) to gain a deeper understanding of the roughness effect on the flow structure. Stereoscopic Particle Image Velocimetry (SPIV) and Acoustic Doppler Velocimetry (ADV) were used. While concentrating on the roughness effect, efficiency and performance of the two velocity measurement methods were verified as well. Spanwise instantaneous velocity is presented in [cm/sec] unit in contour diagrams.

Task #1

ADV test was conducted in a bare flume without any roughness. The ADV result is depicted in Fig. 1. The area that ADV measurement cannot reach on the right, left, top and bottom are 50, 70, 65 and 20 mm wide, respectively. The test was conducted in 25 Hz sample rate and 1500 sample points. While the ADV is a very reliable piece of equipment, its measurement near the wall may consist of greater error than usual and should not be relied upon.

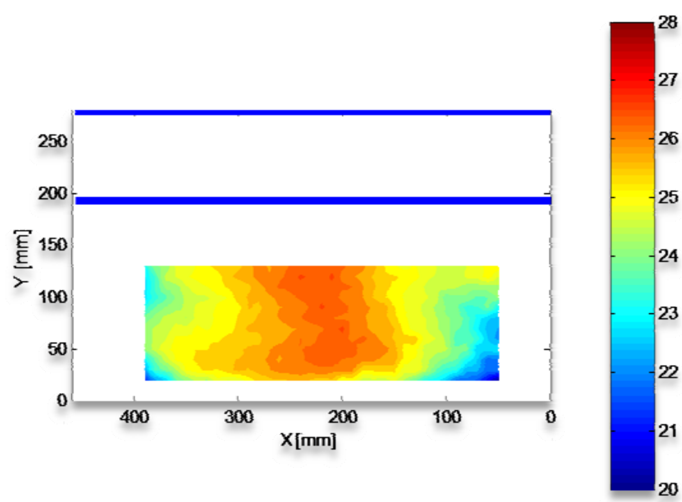

Fig. 1 ADV total velocity for a rectangular section without roughness

Task #2

The PIV result is shown in Fig. 2. The time duration of the test was 30 seconds. 900 images for each camera were analyzed. The measurement from a 64mm-wide strip is missing because of obstructed line of sight.

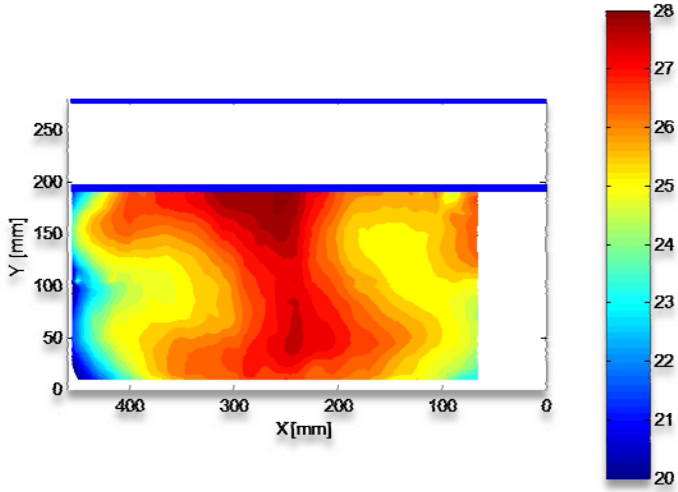

Fig. 2. PIV total velocity for a rectangular section without roughness

Task #3

For the 3rd test, roughness was included by spreading gravel on the bed. Sieve analysis was conducted and resulted a D_{50} of 10.6 mm instead of specified 12mm when it was purchased. ADV result is shown in the Fig. 3. Note that the discharge and water height was maintained the same as the test without roughness. Data from an area within 15mm from wall are omitted.

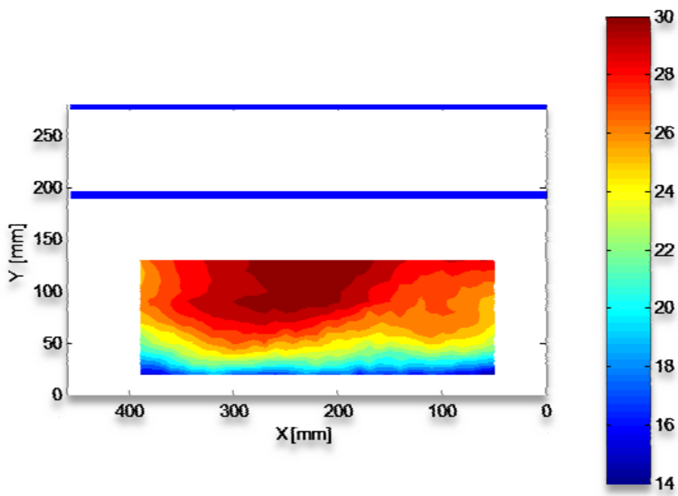

Fig. 3. ADV Total velocity for a rectangular section with roughness

Task #4

Fig. 4 shows the result of the PIV measurement on the rough gravel bed.

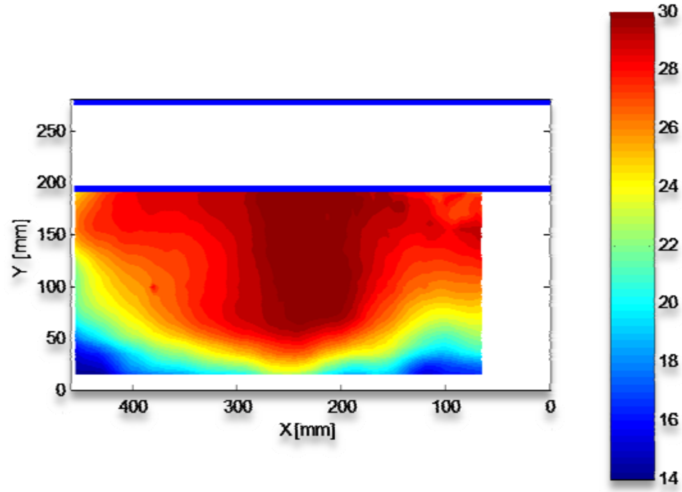

Fig. 4. PIV total velocity for a rectangular section with roughness

Results:

A comparison was made in two phases. The first phase is comparing PIV values with ADV values (with and without roughness) to cross-validate two methods. The second phase is to compare the results without roughness to that with roughness to determine impact from roughness to the flow structure. Since PIV can capture more area than ADV, using PIV results will give us a deeper and extensive understanding of the effect of roughness on the flow pattern. For simplicity and ease of visualization, three vertical lines x=65 [mm], x=230 [mm] and x=390 [mm] from the near side wall of the flume were chosen for point-by-point comparison purpose. Note that, since ADV result could not cover the whole water height (restrictions in practice and near bed poor performance), the PIV results were cropped to match the size of the ADV measurement area. In a later stage, when PIV results from tests with roughness are compared with those without roughness, the entire measurement area would be used.

Phase I

Without Roughness

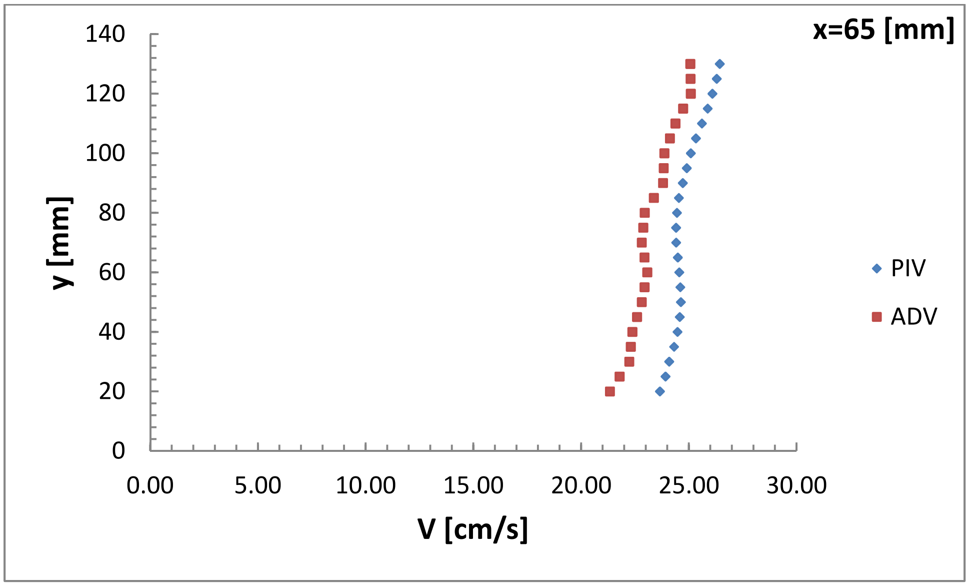

Fig. 5. PIV and ADV comparison for x=65 [mm] station without roughness

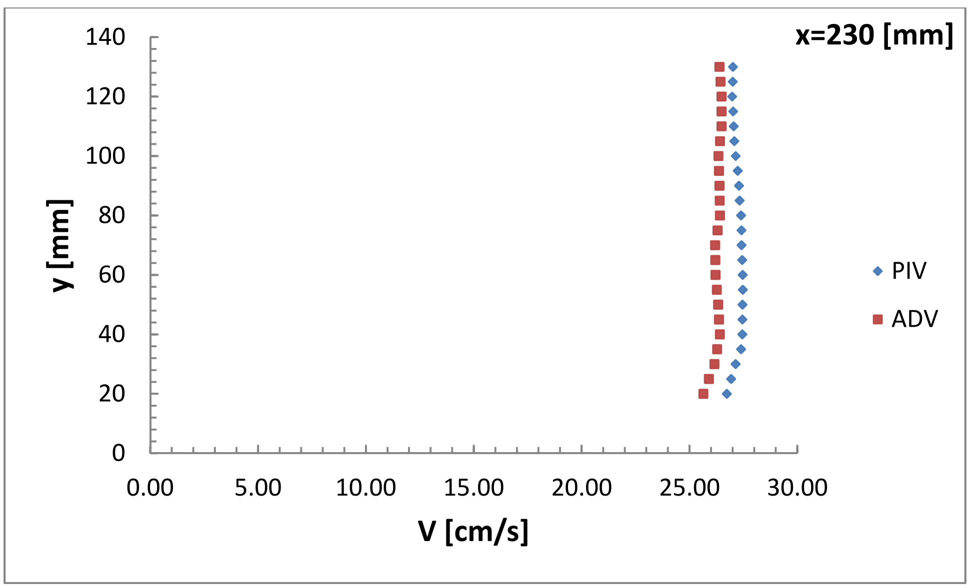

Fig. 6. PIV and ADV comparison for x=230 [mm] station without roughness

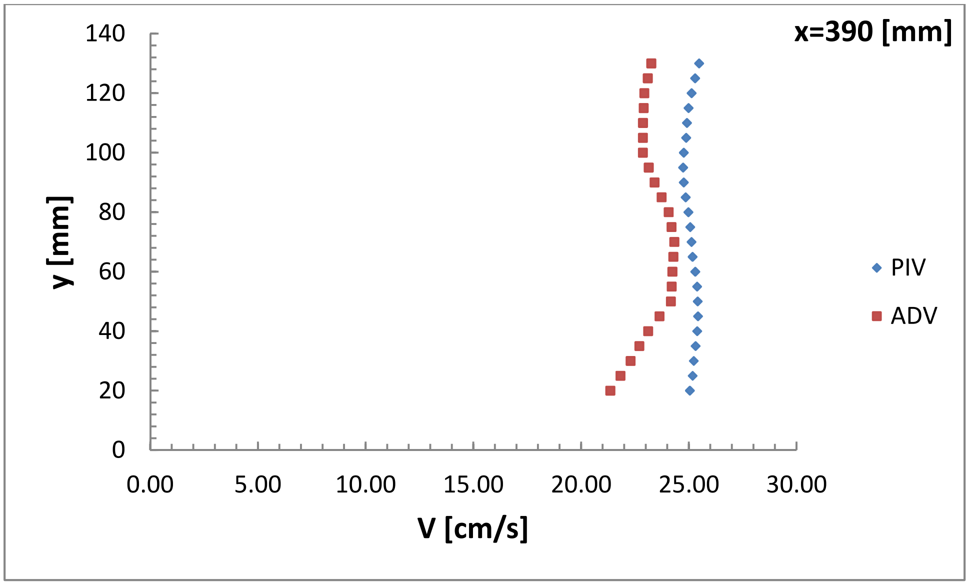

Fig. 7. PIV and ADV comparison for x=390 [mm] station without roughness

With Roughness

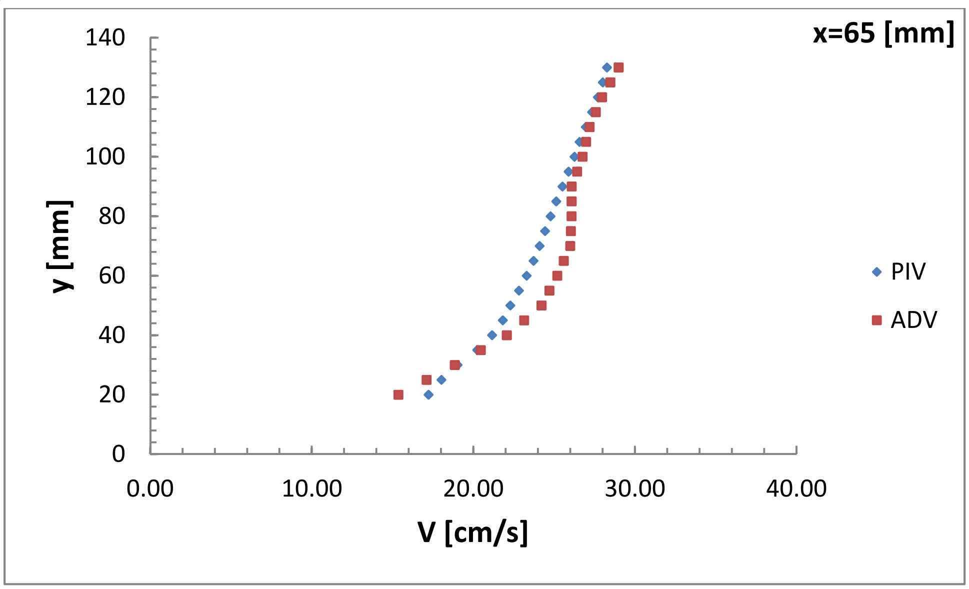

Fig. 8. PIV and ADV comparison for x=65 [mm] station with roughness

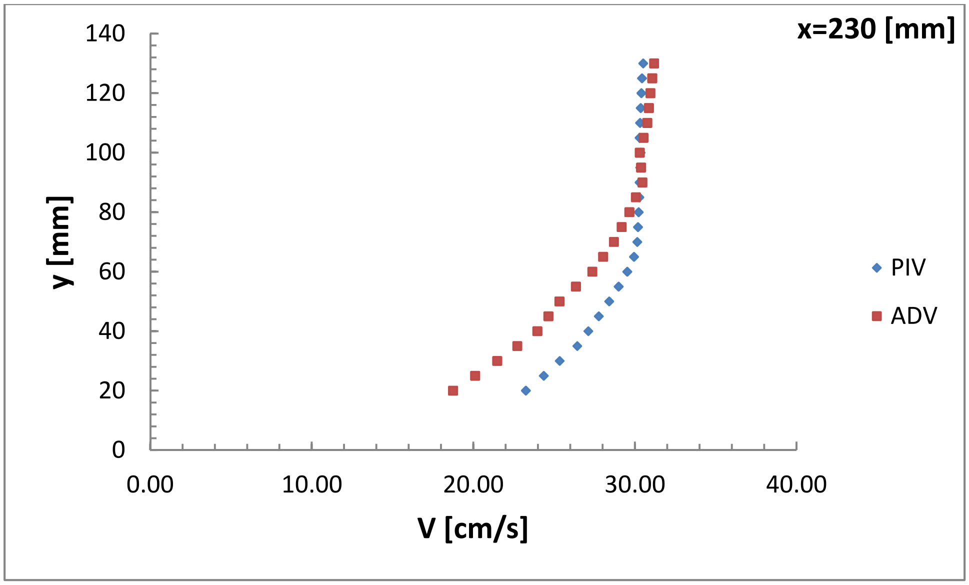

Fig. 9. PIV and ADV comparison for x=230 [mm] station with roughness

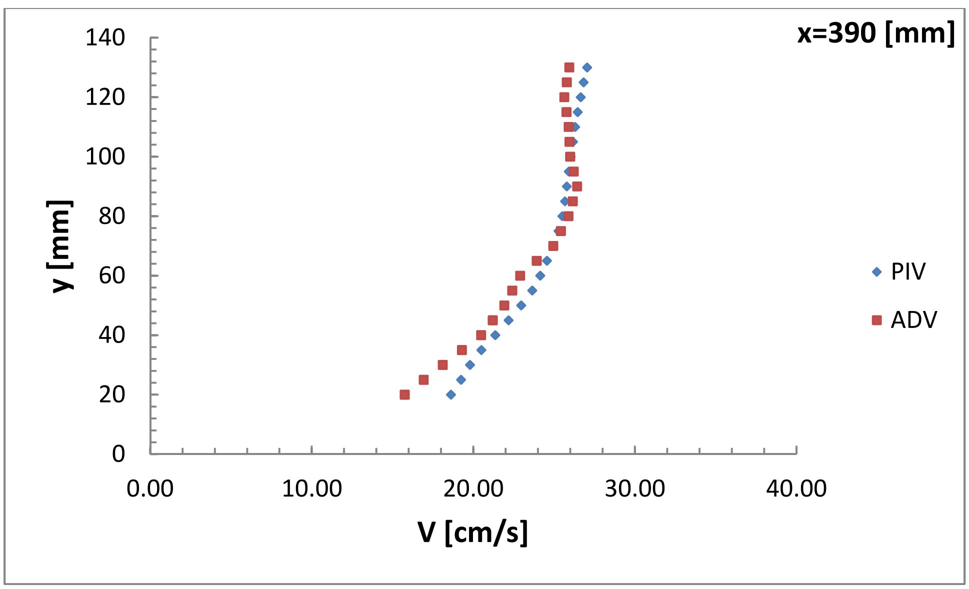

Fig. 10. PIV and ADV comparison for x=390 [mm] station with roughness

Phase 2

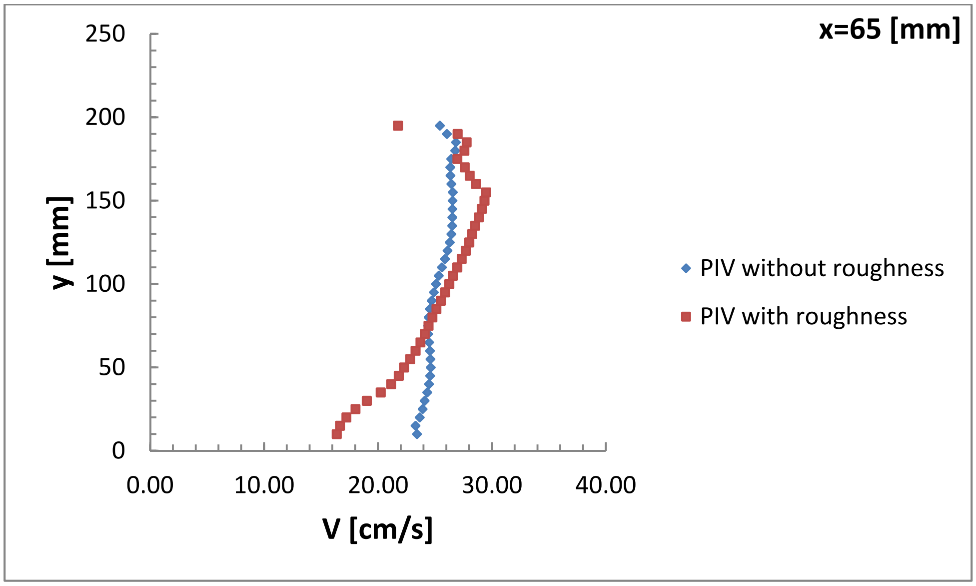

Fig. 11. PIV comparison for x=65 [mm] station for bed both with and without roughness

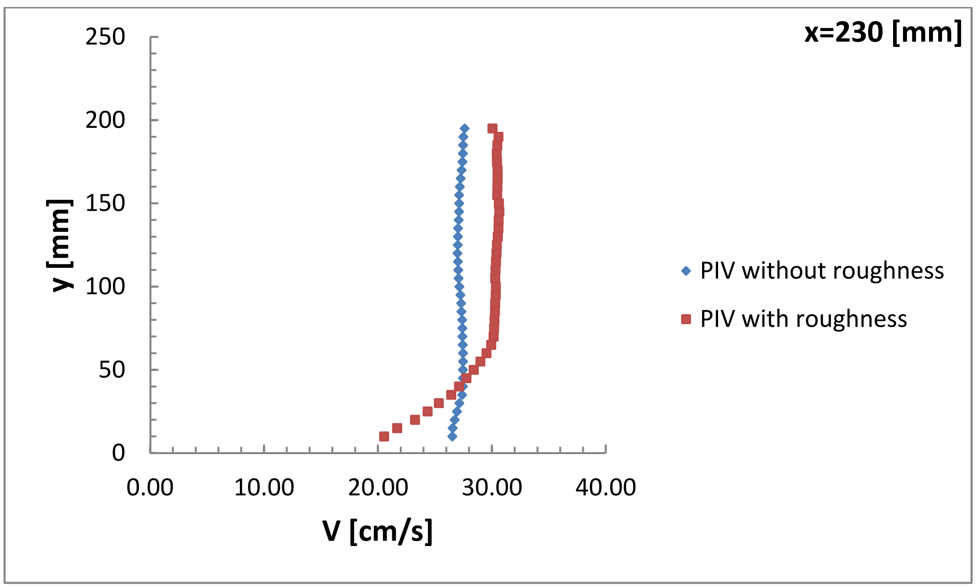

Fig. 12. PIV comparison for x=230 [mm] station for bed both with and without roughness

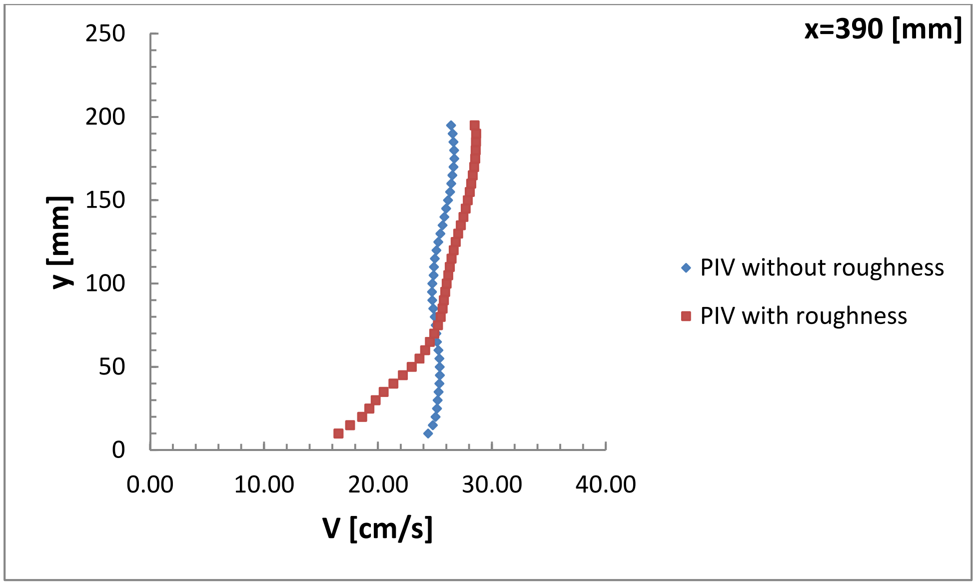

Fig. 13 .PIV comparison for x=390 [mm] station for bed both with and without roughness

Discussion

Fig. 5, 6 and 7 show an agreement between PIV and ADV for the case that roughness does not exist. The error between two methods expected to be around 5% up to 10%. This agreement is much improved when roughness is present (Fig. 8, 9 and 10). It seems that when smooth surface is being used (i.e. bed without gravel) some unevenly distributed kinetic energy induced by the pump is not completely dissipated before reaching the test section. Gravel (or corrugated pipe in later tests) would easily dissipate the small amount of kinematic energy and obtain consistent measurement. Another significant factor would be the spurious illuminations initiated from the smooth and reflective flume bed. Using roughness, which is naturally colored grayish most of the reflections from laser beam, is absorbed eliminating the virtual displacements.

Phase two diagrams (figures 11, 12 and 13) clearly show that in area near the bed, velocity with roughness is lower than that without roughness. On the other hand, in the area near water surface, velocity with roughness is higher than that without roughness. This is because of the setting of the flume to maintain constant discharge. The reduction of velocity near bed caused by the gravel is compensated by the increasing of velocity near surface to maintain the same discharge.

2nd CMP Section Velocimetry Results:

The 2nd CMP section has a bed elevation of 5.4 inch. The sediment bed was simulated by one layer of gravel. The test was conducted with both ADV and PIV.

1st Case Scenario Low Velocity:

The test conditions of the 1st low velocity test are summarized in Table 1.

Table 1 1st case study low velocity

Bed El. [in]	Water Level [in]	Average Velocity [ft/sec]	Wetted Area [in^2]	Discharge [in^3/sec]
5.4	**4.5**	**0.71**	**66.46**	**566.25**

ADV and PIV Results:

Below are the results for the 1st case study. Figure 14 and figure 15 show the ADV and PIV results, respectively. The measurable area of ADV is very small because it cannot not measure the area within certain distances from the surface and from the bed. With shallow water, the remaining measurable area is relatively small.

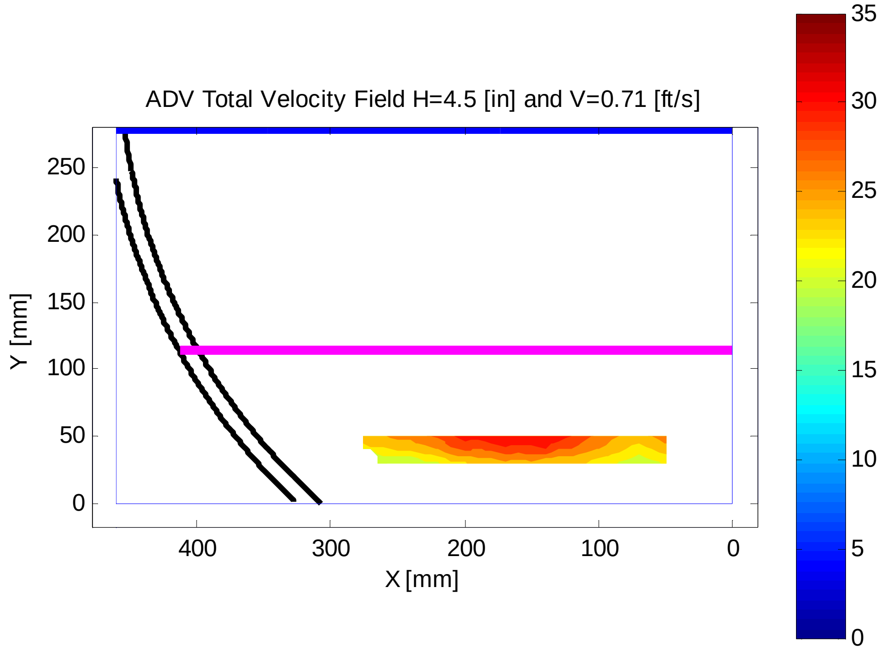

Fig. 14 ADV results for the 2nd CMP section with water height=4.5 [in] and average velocity= 0.71 [fts]

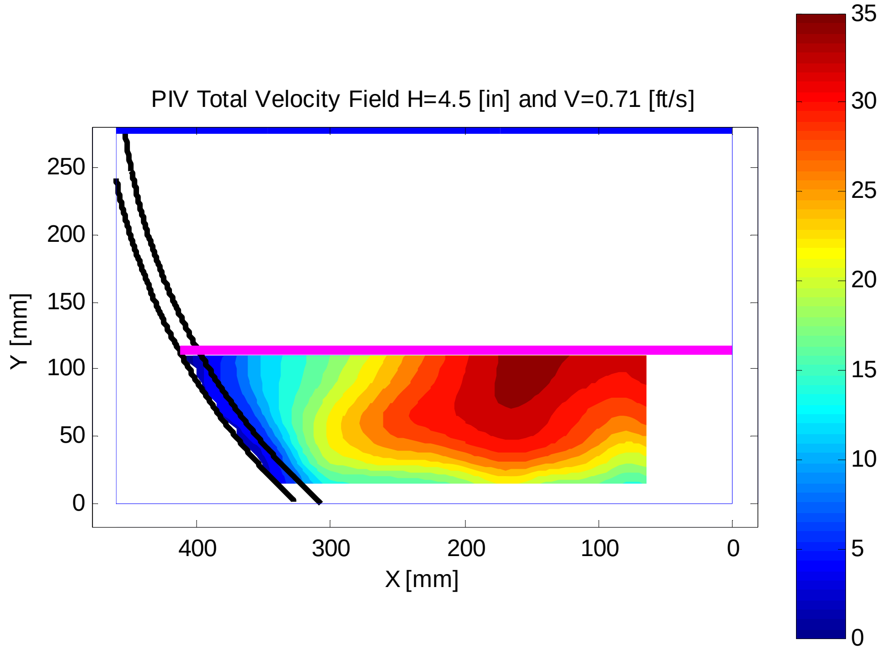

Fig. 15 PIV results for the 2nd CMP section with water height=4.5 [in] and average velocity= 1.1 [fts]

1st Case Scenario High Velocity:

The testing condition of the 1st case study high velocity are presented in Table 2.

Table 2 1st case study high velocity

Bed El. [in]	Water Level [in]	Average Velocity [ft/sec]	Wetted Area [in^2]	Discharge [in^3/sec]
5.4	4.5	1.1	66.46	877.29

ADV and PIV results:

Below are the results for the 1st high velocity test. Figure 16 and figure 17 show the ADV and PIV results, respectively.

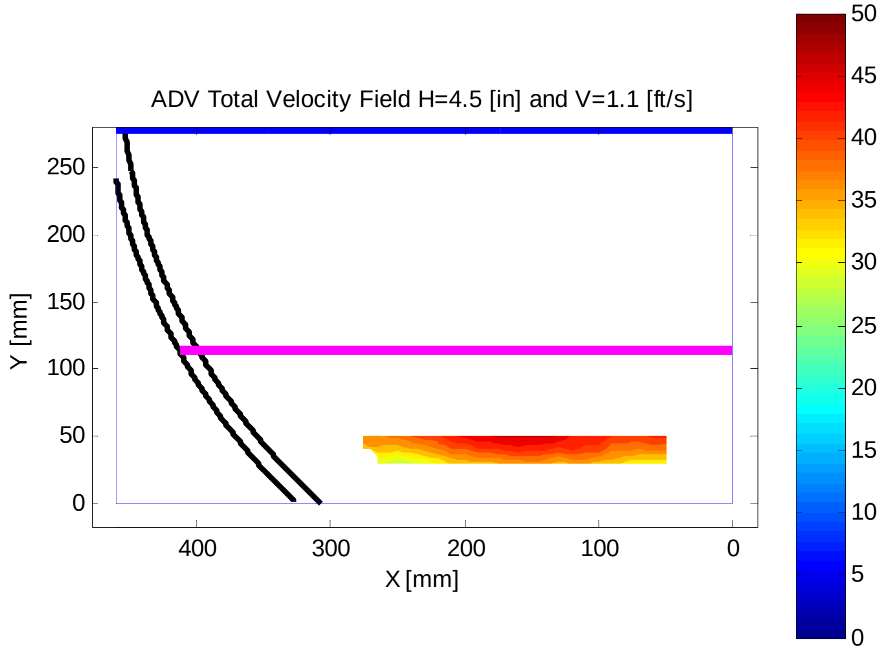

Fig. 16 ADV results for the 2nd CMP section with water height=4.5 [in] and average velocity= 1.1 [fts]

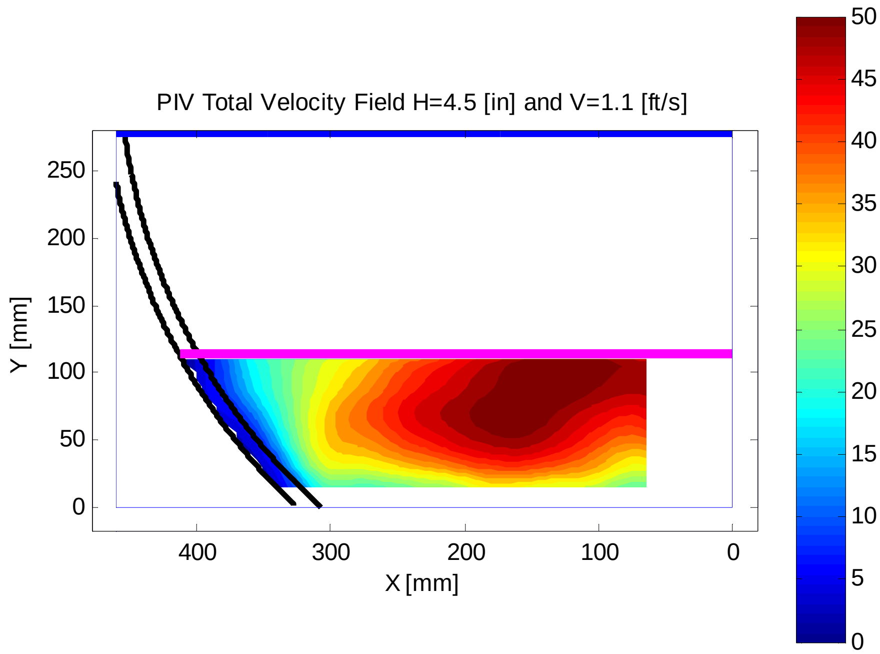

Fig. 17 PIV results for the 2nd CMP section with water height=4.5 [in] and average velocity= 1.1 [fts]

2nd Case Scenario Low Velocity:

The test conditions of the 2nd low velocity test are presented in Table 3.

Table 3 2nd case study low velocity

Bed El. [in]	Water Level [in]	Average Velocity [ft/sec]	Wetted Area [in^2]	Discharge [in^3/sec]
5.4	**6**	**0.71**	**91.34**	**778.22**

ADV and PIV results:

Below are the results for the 2nd case study. Figure 18 and figure 19 show the ADV and PIV results, respectively.

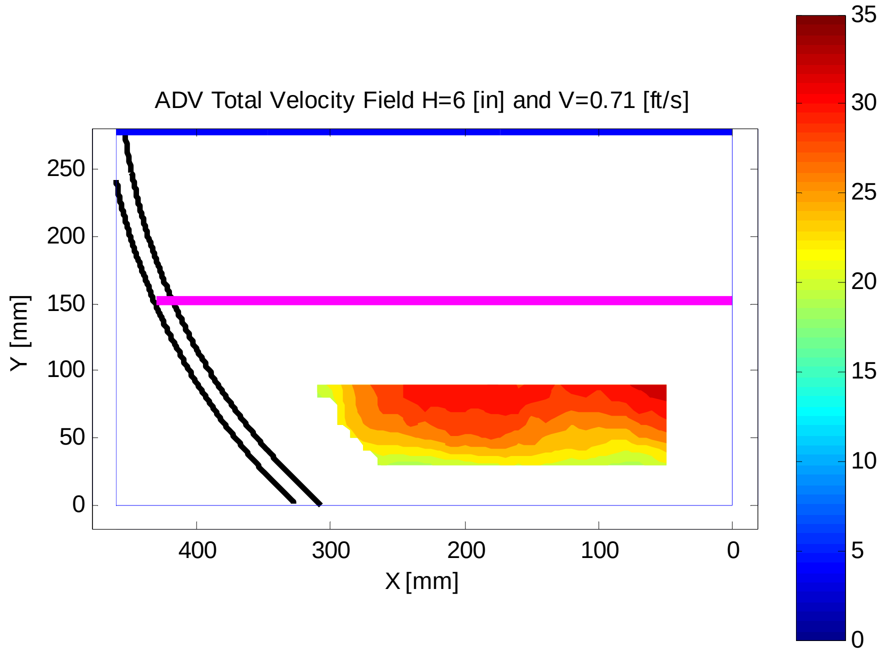

Fig. 18 ADV results for the 2nd CMP section with water height=6 [in] and average velocity= 0.71 [fts]

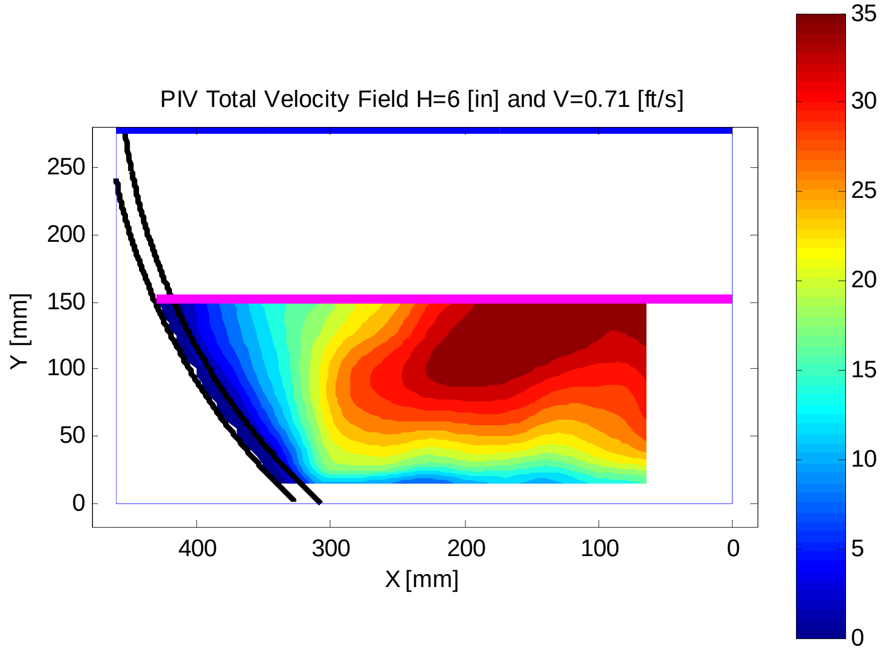

Fig. 19 PIV results for the 2nd CMP section with water height=6 [in] and average velocity= 1.1 [fts]

2nd Case Scenario High Velocity:

The test conditions of the 2nd high velocity test are presented in Table 4.

Table 4 2nd case study high velocity

Bed El. [in]	Water Level [in]	Average Velocity [ft/sec]	Wetted Area [in^2]	Discharge [in^3/sec]
5.4	6	1.1	91.34	1205.69

ADV and PIV results:

Below are the results for the 2nd case study high velocity. Figure 20 and figure 21 show the ADV and PIV results, respectively.

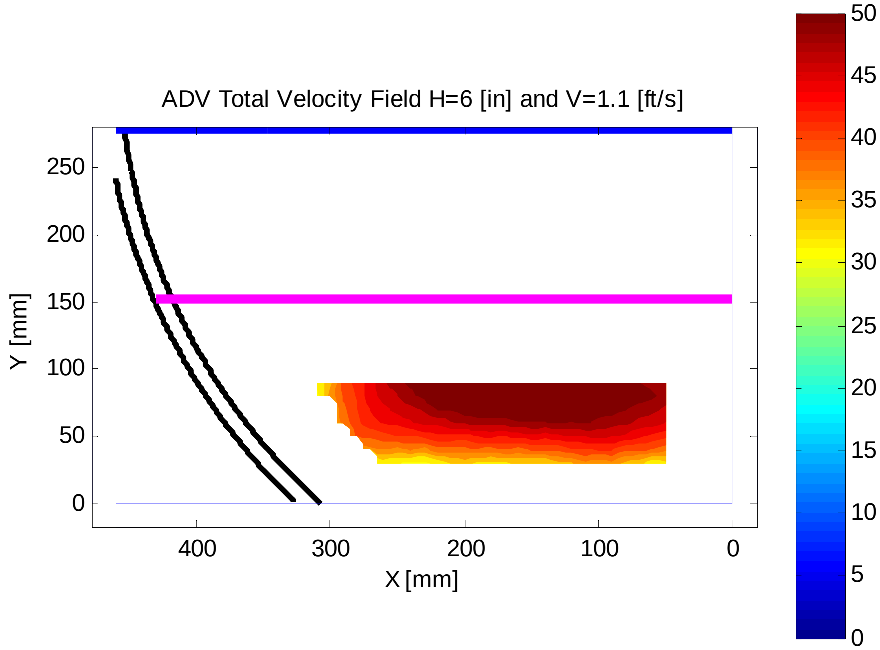

Fig. 20 ADV results for the 2nd CMP section with water height=6 [in] and average velocity= 1.1 [fts]

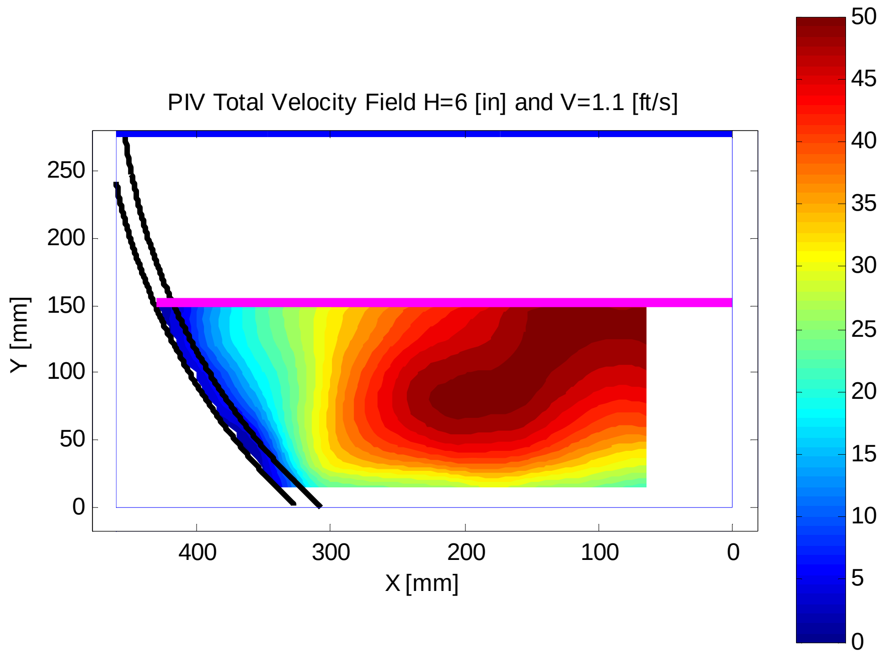

Fig. 21 PIV results for the 2nd CMP section with water height=6 [in] and average velocity= 1.1 [fts]

3rd Case Scenario Low Velocity:

The test condition of the 3rd low velocity test are presented in Table 5.

Table 5 3rd case study low velocity

Bed El. [in]	Water Level [in]	Average Velocity [ft/sec]	Wetted Area [in^2]	Discharge [in^3/sec]
5.4	**9**	**0.71**	**143.61**	**1223.59**

ADV and PIV Results:

Below are the results for the 3rd case study. Figure 22 and figure 23 show the ADV and PIV results, respectively.

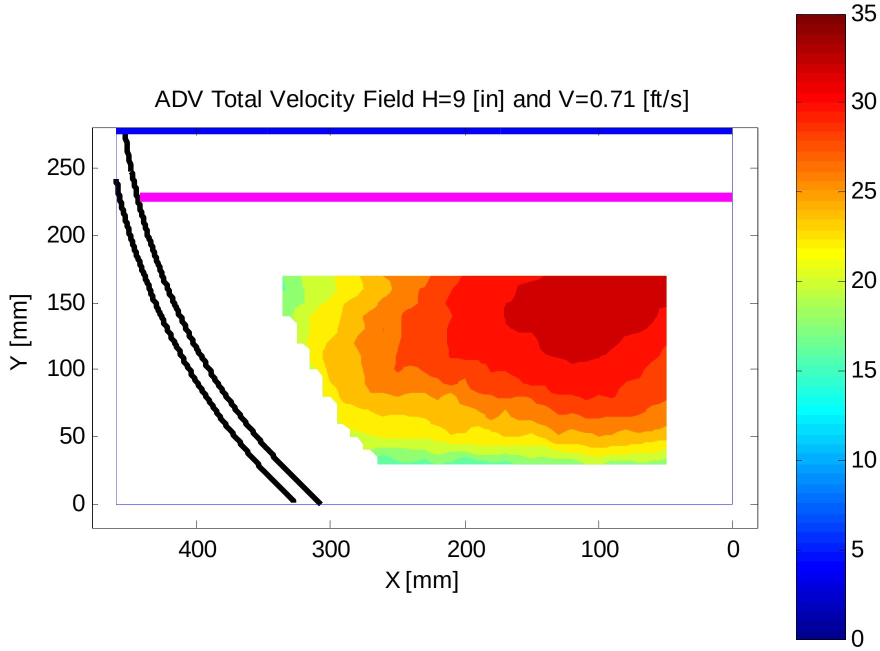

Fig. 22 ADV results for the 2nd CMP section with water height=9 [in] and average velocity= 0.71 [fts]

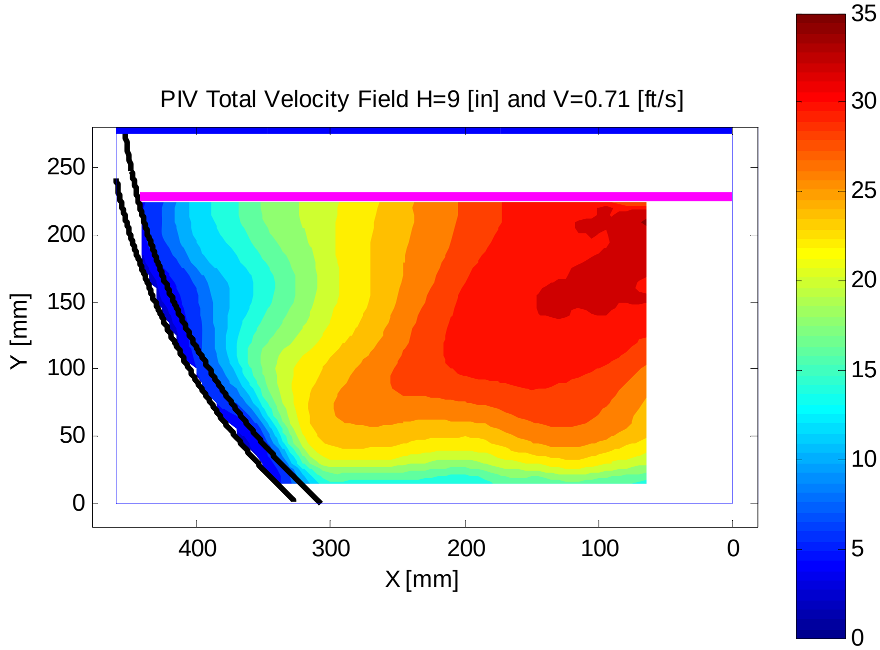

Fig. 23 PIV results for the 2nd CMP section with water height=9 [in] and average velocity= 1.1 [fts]

3rd Case Scenario High Velocity:

The test conditions of the 2nd high velocity test are presented in Table 6.

Table 6 3rd case study high velocity

Bed El. [in]	Water Level [in]	Average Velocity [ft/sec]	Wetted Area [in^2]	Discharge [in^3/sec]
5.4	9	1.1	143.61	1895.70

ADV and PIV Results:

Below are the results for the 3rd case study high velocity. Figure 24 and figure 25 show the ADV and PIV results, respectively.

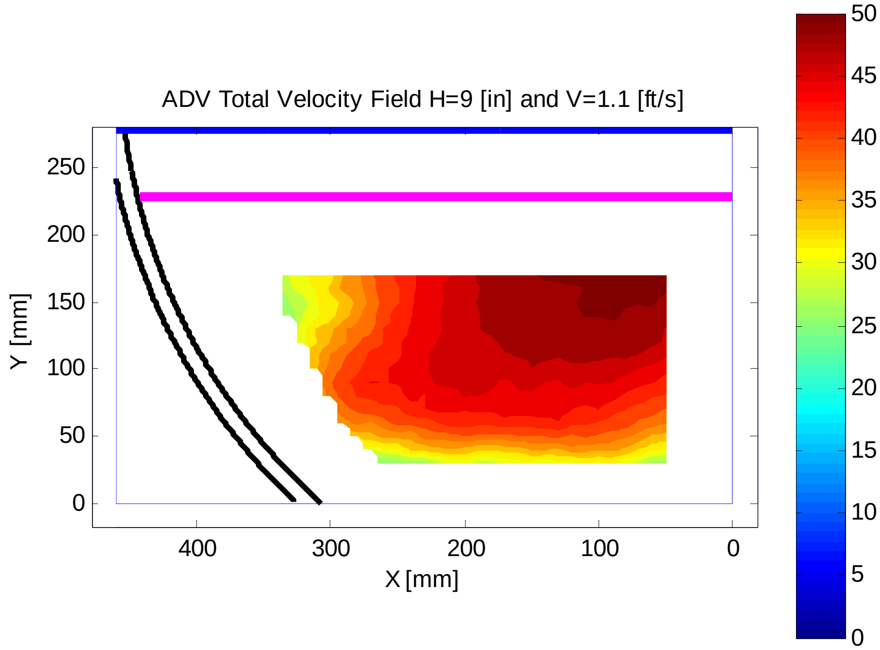

Fig. 24 ADV results for the 2nd CMP section with water height=9 [in] and average velocity= 1.1 [fts]

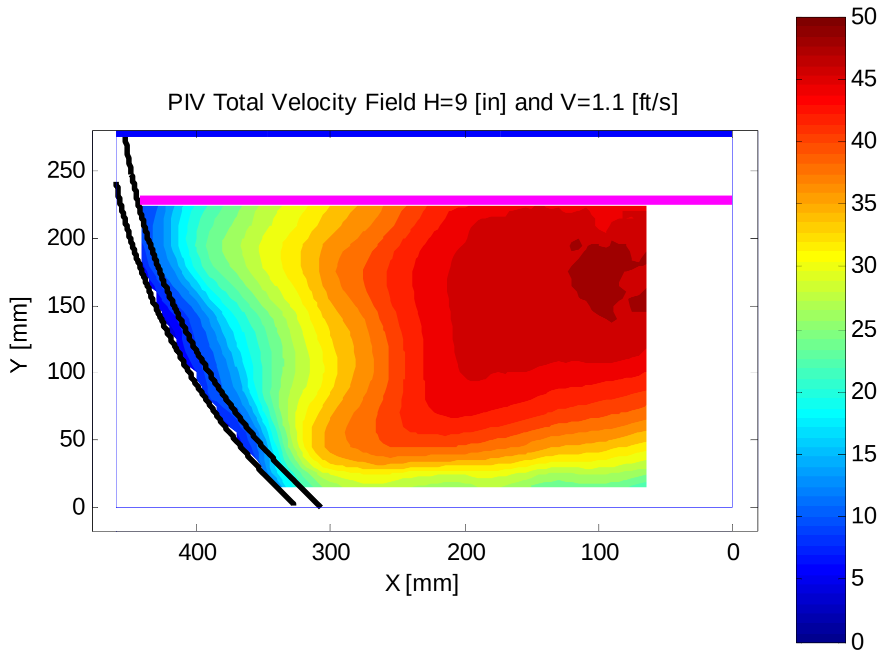

Fig. 25 PIV results for the 2nd CMP section with water height=9 [in] and average velocity= 1.1 [fts]

Discussion:

The results from the physical tests are compared with the results from Computational Fluid Dynamics (CFD) simulation. Since ADV does not cover the complete CMP section, the comparison is made between PIV and CFD results.

Two statistical concepts so called root mean square error and the standard error are introduced.

Root Mean Square Error (RMSE):

RMSE is a statistical concept mostly used in measuring differences between a model and an estimator. In our case, the model will be the physical test (PIV and ADV) and the estimator is adopted as the CFD test.

$$\boldsymbol{RMSE} = \sqrt{(\boldsymbol{V_{PIV}} - \boldsymbol{V_{CFD}})^2} \qquad (1)$$

Normalized Root Mean Square Error (NRMSE) or Standard Error:

RMSE is an index of a goodness of a model. The only drawback for RMSE is being dependent on the dimension. In order to have RMSE in dimensionless form we take advantage of normalized root mean square error or in other words standard error.

$$NRMSE = \frac{RMSE}{V_{max} - V_{min}} \qquad \text{(Error! Bookmark not defined.)}$$

Figure 26 and 27 shows the RMSE and NRMSE, accordingly. The vertical axes unit in figure 26 is [cm/sec]. For the lateral diagram, the unit is percentage.

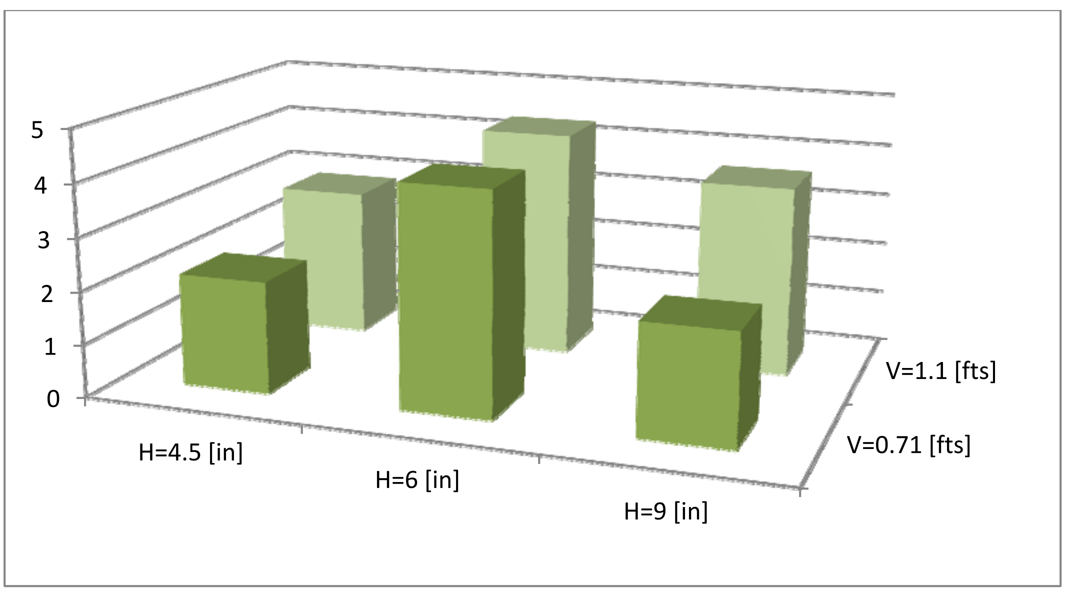

Fig. 26 RMSE between PIV and CFD for the 2nd CMP section

Based on the figure 26, the maximum RMSE is around 4 [cm/sec] which happens in the high velocity of the 6 [in] water elevation CMP test. Moreover, it is well obvious from figure 27 that the maximum standard error between PIV and CFD is less than 9%. In addition to, further analyzing the figure shows that the standard error for all of the 2nd CMP test scenarios are averagely less than 6%, which is a promising error rate considering the complete different nature of the physical and computer simulations.

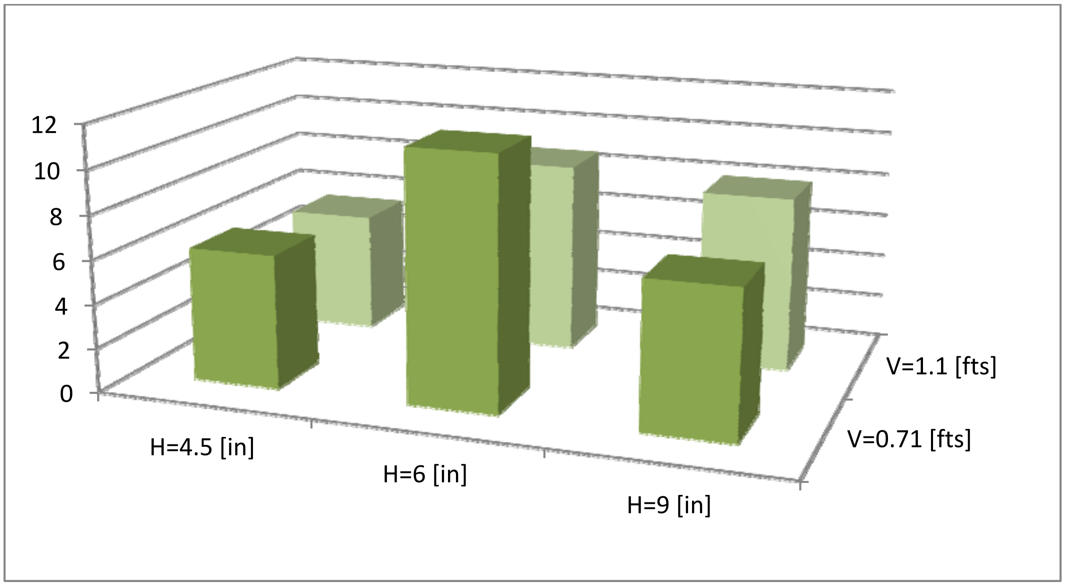

Fig. 27 NRMSE between PIV and CFD for 2nd CMP section

Time Schedule Progress:

Table 7 depicts the planned schedule and the project progress. Draft of final report is expected to be ready by the end of May 2012.

Table 7 Time schedule and progress chart for the fish passage in large culverts with low flows

Task																		
Year	2010	2011												2012				
Month	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Construct Model Pipe	100%																	
Flume Tests according to Test Matrix		Progress 75%																
CFD Experiments according to Test Matrix	Progress 60%																	
Data Analysis and Recommendations for Implementation	Progress 50%																	
Preliminary Draft Report																		
Final Report																		