



## TECHNIQUES TO HANDLE ADV MEASUREMENTS DATA

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### المخلص

تعتبر الانواع المختلفة من مقياس السرعة الصوتي ADV أجهزة قياس هيدروليكية متميزة. تستخدم لقياس توزيع السرعة والاضطراب لحساب اجهادات قص الاضطراب في الترع المعملية والممرات المائية الصناعية والطبيعية. دائما تلاحظ مشكلة تحويل بيانات ADV إلى ملفات متعارف عليها. في هذا البحث تم استخدام تقنيتين لحل هذه المشكلة. الأولى استخدام برنامج WinADV في حالة الأجهزة القديمة والثانية نموذج تم تصميمه وتطويره على الماتلاب في حالة الأجهزة الحديثة. أجريت مجموعتان من التجارب المعملية لتطبيق التقنيتين المقترحتين. الأولى تم تطبيقها على حالة السريان أمام المفيض ذو المدخل الصندوقي والثانية على حالة السريان في الترع المغطاة جزئيا. أثبتت التقنيتان قدرة جيدة على التعامل مع بيانات ADV

### ABSTRACT

Down-looking (flexible and rigid) and Side-looking (flexible) Acoustic Doppler Velocimeters, ADV, are powerful hydraulic measuring devices. They are used to measure the flow velocity distribution and turbulence, to determine turbulence shear in laboratory flumes and field natural and artificial streams. In using these measuring tools, it is always experienced the problem of transferring measurements data from ADV pulses to regular data files. This process is called ADV data post-processing. In this paper, two techniques were used to solve this problem. The first is using the WinADV software in case of the rigid old version of ADV with file extension \*.adv. The second is a new technique using Matlab programming to deal with flexible new versions of ADV with file extension \*.ntk and \*.vno. Two sets of laboratory ADV measurements were conducted to apply the suggested techniques. The first technique was applied to the case of flow upstream a box inlet spillway and the second to the case of flow in partially covered trapezoidal open channel. The two techniques proved good capability in ADV data post-processing.

**KEY WORDS:** Velocity and turbulence distribution, ADV, Data handling, Spillways, Partially covered open channels.

### INTRODUCTION AND LITERATURE REVIEW

With the evolution of nowadays development and use of software computer packages in hydraulic simulation, the need to accurate field and laboratory data has been growing rapidly. This data is being used in calibration and verification of the software to raise the level of certainty prior to use in scientific research and engineering applications. Distribution of flow velocity and turbulence are among the most important types of data to describe the flow regime.

Since their introduction in 1993, Acoustic Doppler Velocimeters (ADV) have quickly become more valuable tools through the years for laboratory and field investigations of flow in rivers, canals, reservoirs, the oceans, and around hydraulic structures and in

laboratory scale models (**Wahl 2000**). ADVs are powerful measuring devices that are used due to their capability of measuring precise mean values of water velocity in three dimensions even at low velocities (**Kraus et al. 1994 and Lopez and Garcia 2001**). ADV is always preferred over other devices, such as Particle Image Velocimeter, due to its simplicity of use and high-precision in three dimensional velocity measurements.

In using ADV, some aspects such as spikes and Doppler noise presence and filtering effects are very important to characterize turbulent flows (**Goring and Nikora 2002**). According to **García et al. 2005**, any ADV produces a reduction in the water velocity signals due to the fact that the temporal averaging process acts as a low-pass filter. ADV measures velocity components ( $V_x$ ,  $V_y$ ,  $V_z$ ) of the velocity vector and reports them using a pulse-coherent technique. ADV technology is based on a dual pulse-pair scheme with different lags separated by a dwell time (**McLelland and Nicholas 2000**).

Many techniques are used to post-process ADV data and transfer these pulses to readable table data files to be used easily and safely in scientific research and engineering practice. The first attempt was by Wahl who designed the most common used software tool in post-processing ADV data called WinADV. It became available to the public in 1996 (see **Wahl 2000**). It is designed for post-processing SonTek and Nortek ADV's real time data files (\*.adv files) and to offer a very strong filtering and processing options. **Voulgaris and Trowbridge 1998** analyzed the acoustic pulse system of ADV. The system operates by transmitting short acoustic pulses along the transmit beam. As the pulses propagate through the water column, a fraction of the acoustic energy is scattered back by small particles suspended in the water. The phase data from successive coherent acoustic returns are converted into velocity estimates using a pulse-pair processing technique. Their technique focused on determining the source of noise and trying to minimize it. Finally, they applied their technique to simple ADV laboratory measurements and compared them to LDA data. **Chanson 2008** developed an ADV data files post-processing tool for turbulence analysis of estuarine flows. It went through three stages. First, velocity signal check: the ADV velocity data can be cleared by removing all communication errors, low signal-to-noise ratio data (<5 dB) and low correlation samples (<60%–70%). Second, Event detection and removal: the effects of major disturbances which may include navigation, probe movement, aquatic life activities are removed. Third, small disturbance detection and removal: for every velocity element, the signal is filtered with a low-pass/high-pass filter threshold. He finally applied his technique to a series of simple field measurements in the estuarine zone of Eprapah Creek, Australia. **Monteroa et al. 2014** extended the technique of **García et al. (2005)** by incorporating spatial and temporal averaging processes in the analysis. A conceptual model, simulating the flow field with Direct Numerical Simulation (DNS) and sampling with ADV, was developed. They considered the effects of spatial and temporal averaging processes (filtering) implemented in ADV on the computations of the turbulent kinetic energy, velocity variances (in the stream-wise, span-wise and vertical direction), and Reynolds shear stresses. More research exploring ADV capabilities are in the works by **Nikora and Goring 1998, Doroudian et al. 2010, and Parsheh et al. 2010**.

This paper introduces two post-processing techniques for ADV data files. It applies them to two sets of simple laboratory measurements conducted in two different cases. In case (A), the ADV data upstream of box inlet drop spillway is post-processed using the old, well-known WinADV software. In case (B), the ADV data of flow in partially covered trapezoidal open channel is post-processed using a new MatLab code. It is

hoped to give a new insight to the ways of ADV data handling to researchers and hydraulic engineers.

## **ADV DATA POST-PROCESSING USING MATLAB PROGRAMMING**

As mentioned above, in case (B), ADV data of flow in partially covered trapezoidal open channel was collected. The used ADV types were Nortek Vectrino II profiling ADV and Nortek Vectrino+ side-looking ADV. These devices produces \*.ntk files and \*.vno files respectively. As reported by **Wahl 2000**, it is experienced that files with extensions rather than \*.adv are hard to be post-processed by WinADV software. This brought about the need to a new programming tool to easily and safely deal with these ADV pre-mentioned types of data. A co-product MatLab code was designed. The code goes through three main steps; identify and remove bad cells, de-spiking and noise removal based on the correlation (COR) and sound-to-noise ratio (SNR), and compile results in form of MatLab file or excel sheet. These steps are conducted through consecutive sub-steps using MatLab scripts. Some important scripts are summarized hereafter:

### 1. Pre-Post-Processing

Structure: Select and save .vno or .ntk file. Then, when open, data and configuration would be obtained.

File-Selecting-Menu: Select file and pass to file-processing.

### 2. Post-processing

Identify and Remove: Go through the selected folder and identify and remove bad cells, such as weak spots, low COR, and low SNR. Then save data with no problem point over the original file.

Remove Extra Time: Remove the first and last bits of extra velocity measurements from data collected using a fixed time for travel rather than waiting for a signal to start (i.e. for the Vectrino+ rather than the Vectrino Profiler).

Orientation Change: Correct the velocity names and directions for data collected with the side-looking Vectrino ADV in its non-standard position. Read in multiple files during one run and use the orientation section of the name to determine the appropriate transformation. Toggle a data orientation field in the data structure from 0 (indicating the local coordinate system) to 1 (indicating the data has been transformed to the global coordinate system). If transformed data is transformed again, the orientation field will go back to 0. In this way, the user is able to know which coordinate system the data is referring to.

File-Processing-Goring-Menu: These functions were designed in the light of **Goring and Nikora 2002** method. This method is basically about plotting the velocity in the three dimensional phase space with its derivatives (first and second). These points are plotted forming a cloudy oval. Some of the points fell away from the anticipated extents of the main body of the oval and get marked as spikes. Then, they get replaced with the mean of the time series. This process keeps on working until no new spikes are acknowledged. Often, from 1% to 3% of the plotted points in a time series are acknowledged as spikes.

Orientation Change 2: The same of Orientation Change but for de-spiked results data collected with the down-looking ADV.

Side Coordinate Fix: Go through the results files for data collected using the Vectrino Profiling ADV in the side-looking orientation and correct the coordinates to reflect that the profile is in the lateral direction rather than the vertical direction.

Compile-Results-Menu: Combine each cross-section results into their separate file. Combine all results into one file per test.

## **EXPERIMENTAL WORK**

Simple laboratory experiments were performed to get ADV data to apply to the two suggested techniques. Experiments were conducted in the Hydraulics Research and Testing Facility at the University of Manitoba, Winnipeg, Manitoba, Canada. As mentioned before, two cases were measured; case (A) and case (B).

### **Case (A): ADV Data Upstream of Box Inlet Drop Spillway**

Box inlet spillway is used for small dams and provides an economical means of passing large flows through the dam with relatively small head increase. Discharge over spillway is controlled by the flow field in the upstream. In case (A) experiments, ADV data (three dimensional velocity and three dimensional turbulence) upstream box inlet spillway was measured and WinADV software was used for data transfer from ADV pulses to regular data file (data post-processing).

Case (A) experiments were executed in a variable slope flume with bed made of steel and covered with Plexiglas sheets and two Plexiglas sides. The flume is 0.95m wide, 0.75m deep and 14m long. The slope was held at approximately 0.72%. The flume discharge capacity is about 150 L/s and water level can be controlled with a louvered tailgate.

SonTek, down-looking with a fixed rigid stem ADV, was used. It is a bit old version of ADV devices that reports data as \*.adv files. It was mounted on a moveable cart and point gauge for easy movement in the three directions manually. The ADV was programmed to take measurements at a frequency of 50 Hz, corresponding to 3000 samples per minute.

Two models for rectangular box inlet spillways with different lengths were constructed of plywood sheets, held together with screws and secured in the flume by clamping the sides of each physical model to the walls of the flume. The construction effort was focused on the upstream portion of the spillway to coincide with the objectives of this experiment, with no construction details added in the downstream, such as spillway stilling basin. The discharge was fixed to 70 L/s.  $W$  is the box width and was fixed to 0.33m.  $L_1$  and  $L_2$  are the box lengths and were taken 0.6m and 0.3m for the large and small models respectively. In both Models, sill level is 0.3m over flume bed.

A convergence test was executed to get sampling time at each measurement. It showed that the reasonable sampling time with accepted tolerance is 4 min (12000 samples). Preliminary runs were performed to check symmetry of the velocity fields around the models. As the max percent difference was 4%, it was decided to measure ADV data of half the flume. Fig. (1) shows dimensions of the two models together with the locations of the ADV data measurements for both large and small models. Four vertical z-direction locations were used for measurements at every location, namely 0.15, 0.25, 0.35, and 0.45m measured from the flume bed. During any of the measurements, the signal to noise ratio (SNR) was monitored to be above 20% to get good quality data.

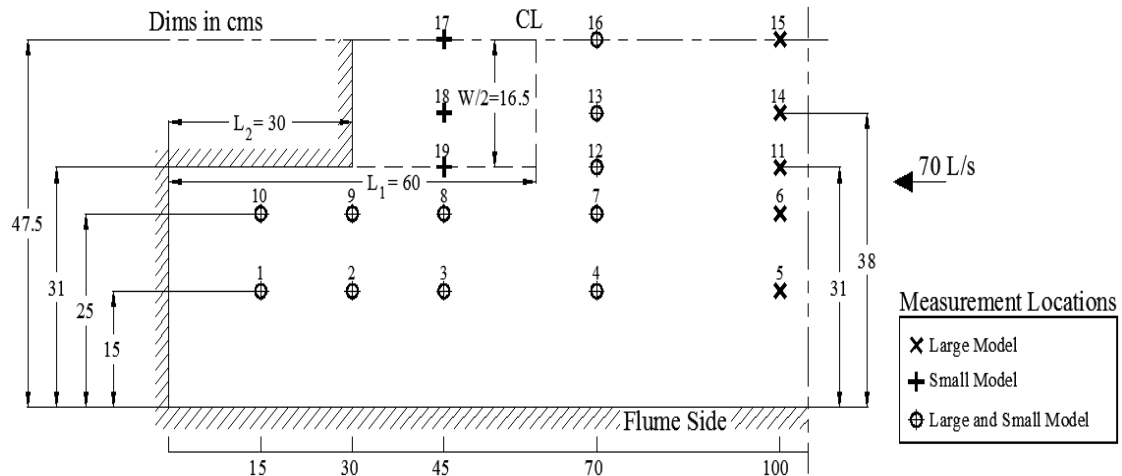


Fig. 1: Dimensions and Measurement Locations in Box Spillway Models

### **Case (B): ADV Data in Partially Covered Trapezoidal Open Channels**

Partially covered open channels exist in warm and cold regions around the world. In warm countries, open channels are sometimes partially covered with weeds while in cold countries, streams are partially or totally covered with ice. In case (B) experiments, simple ADV data in selected section of partially covered trapezoidal open channels was measured and the new Matlab code was used to post-process data (convert data from ADV pulses to regular data file).

Case (B) experiments were executed in a 14m long, 1.2 m wide plywood flume with a bed slope of 0.25% and a tailgate to control water level. Inclined plywood sheets with side slope 3:2 were used to form the trapezoidal sides.

New versions of ADV devices were used; Nortek Vectrino+ side-looking ADV (used also in the up-looking direction) and down-looking Nortek Vectrino II ADV. They produced data with extensions \*.ntk and \*.vno respectively. In order to have a better way with the orientation of the ADV, flexible cables were used instead of the old known rigid ones. Two models were tested; one was a complete open channel and the other was partially covered. The cover extended 12.5% from the two sides. That is 25% of the top width was covered. The cover was made by smooth plywood sheets and was placed to be partially submerged in water. The ADV was attached to a computer customize transverse mechanism in order to move the ADV through the sampling locations automatically. The discharge was fixed at 55 L/s and water depth at 0.2m giving Froude number = 0.25. Fig. (2) shows the sampling locations used in the experiments and the ADV types used in data collection. The locations were selected such that more measurements are carried out near the two flow boundaries; flume bed and water free surface (or the cover) where the variations in flow fields and turbulence are expected to be sharp. That is 12 ADV measuring data were collected in the top and bottom 50mm, while only 5 measuring data were collected in the middle 100mm. Convergence test showed that good sampling time with accepted tolerance at each measurement is 3min giving 9000 samples' readings.

### **ANALYSIS AND DISCUSSION**

Post-processing of the ADV data files is considered the most important part for the ADV user to make the ADV data files readable and easy to use with any widely known software like Excel for instance. This paper suggests the use of two different post-processing techniques.

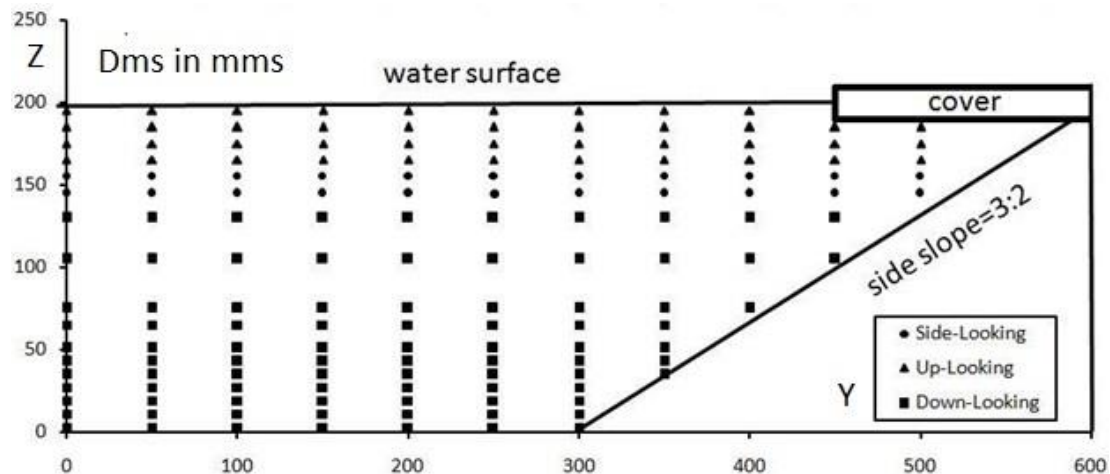


Fig. 2: Sampling Locations in Case (B) and the Used ADV types

The first technique is the use of WinADV software in old ADV file data types with extension (\*.adv) resulting from the use of SonTek ADV. The process goes in two steps; first create a file called Filtered.Sum (or similar)“\*.sum” file (summary file) by WinADV. Second, open it using Excel as a semicolon delimited file and get \*.xls (Excel) file.

This technique fails to deal with new ADV versions with new extension files. So, a second technique is suggested. In the second technique, the new versions of ADV; Nortek Vectrino II profiling ADV and Nortek Vectrino+ side-looking ADV (used also in the up-looking direction) result in \*.ntk files and \*.vno files are post-processed using a new software developed and coded on MatLab.

**Case (A): Hydraulic Analysis of ADV Data Upstream of Box Inlet Drop Spillway:**

The first technique was used. Figs. (3, 4, 5) show the distribution of the three average velocity components  $V_x$ ,  $V_y$ ,  $V_z$  at points 9, 15, 16 of Fig. (1) respectively. These points were selected as three examples for large spillway model where point 9 represents the side points and points 15, 16 represent the front points. Every point in the figure represents the average of 12000 ADV sample readings as measuring time was 4min. As expected, the main stream component,  $V_x$ , increases with the vertical distance above flume bed,  $Z$ . The values of the velocity component in transverse direction,  $V_y$ , and vertical direction,  $V_z$ , are so small that they may be neglected except at point 9. At point 9, values of  $V_y$  and  $V_z$  are large as they are responsible for changing the direction of flow and reorient it to fall over the box spillway crest. The values of  $V_z$ , between  $Z = 30\text{cm}$  and  $45\text{cm}$  are highly negative denoting the direction of the fall down into the box. Figs. (6, 7, 8) show the variation of the three turbulence components  $V'_x$ ,  $V'_y$ ,  $V'_z$  with vertical distance,  $Z$ , for the same selected points. The given values represent the Root Mean Square (RMS) of turbulence. In front points, the value of turbulence in x-component is maximum between level 25cm and 35cm. This is reasonable denoting that the level of the spillway crest is 30cm over the flume bed and hence, this is the zone of maximum change in velocity values (turbulence). In side point, the max value of turbulence is in the zone under the spillway crest as the max change takes place for the dead zone to exist.

Approximately, the same may be noticed for Figs. (9, 10, 11) and Figs. (12, 13, 14) in the case of small spillway model. Comparing the  $V_x$  component in the two models of point 16 as an example, it is noticed that  $V_x$  curve slope is sharper in large model than that of small one. That is the value of  $V_x$  of the large model is less near the bottom and

more near the surface than the small model. That is due to the variation of the length of the two models bringing about change in the distance between point 16 and the spillway. The nearer is the point from the spillway the more the value of velocity in the upper zone and less the value in lower zone. It is clear that WinADV succeeded in post-processing old version ADV data with extension \*.adv.

**Case (B): Hydraulic Analysis of ADV Data for Flow in Trapezoidal Open Channels**

The second technique was used. Figs. (15, 16) represent the distribution of the main stream component,  $V_x$ , at points with  $Y$  (distance from centerline) = 0, 150, 300, 400, 450 mm for the two tested models; one with a complete open channel and the other with partial cover. The values of the two other components  $V_y$  and  $V_z$  were noticed to be so small that they were neglected. This tells that the selected measurements' section was in the fully developed flow zone. On the other hand, the three turbulence components were also found very small. This is as the plywood boundaries of both the flume and the cover were ultimately smooth. The  $V_x$  distribution with the vertical distance,  $Z$ , shows normal distribution in smooth open channels especially near the flume centerline. Comparing results of the two models, small increase of the velocity in partially covered model than the totally opened one is noticed.

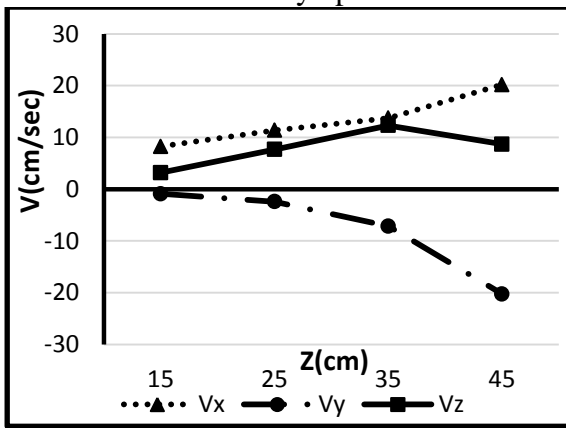


Fig. 3: V versus Z (Pt. 9 Large Model)

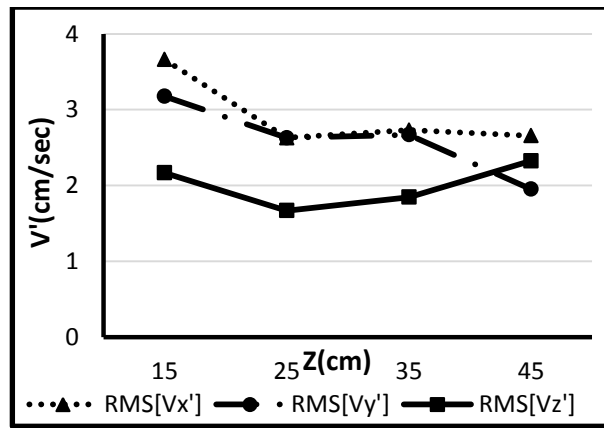


Fig. 6:  $V'$  versus Z (Pt. 9 Large Model)

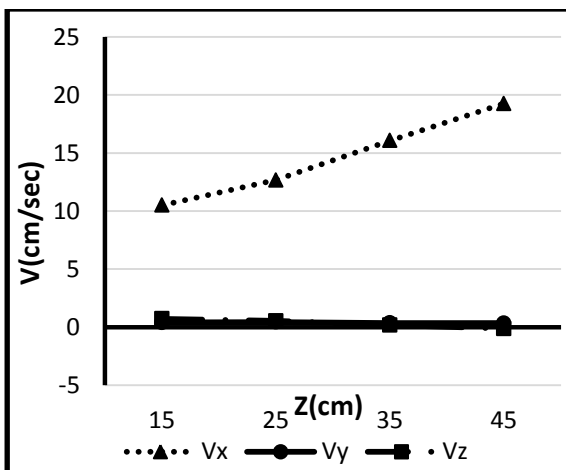


Fig. 4: V versus Z (Pt. 15 Large Model)

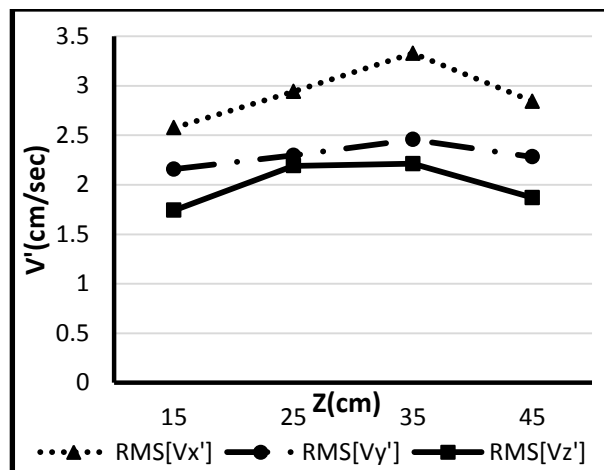


Fig. 7:  $V'$  versus Z (Pt. 15 Large Model)

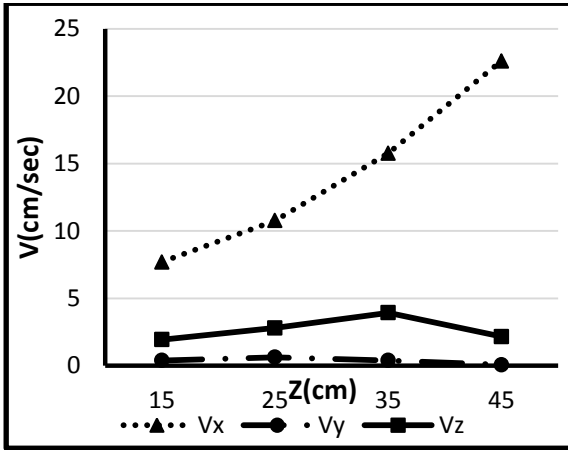


Fig. 5: V versus Z (Pt. 16 Large Model)

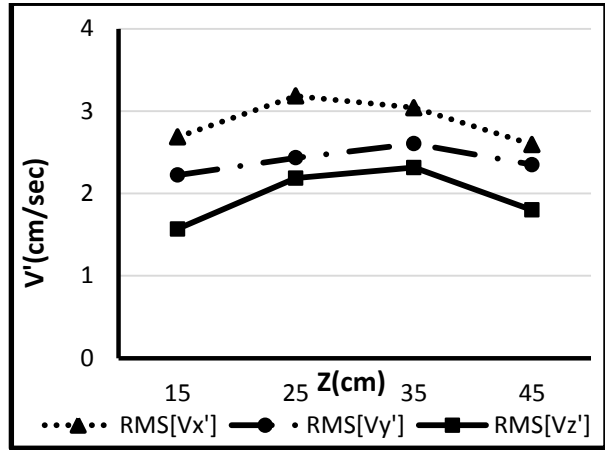


Fig. 8: V' versus Z (Pt. 16 Large Model)

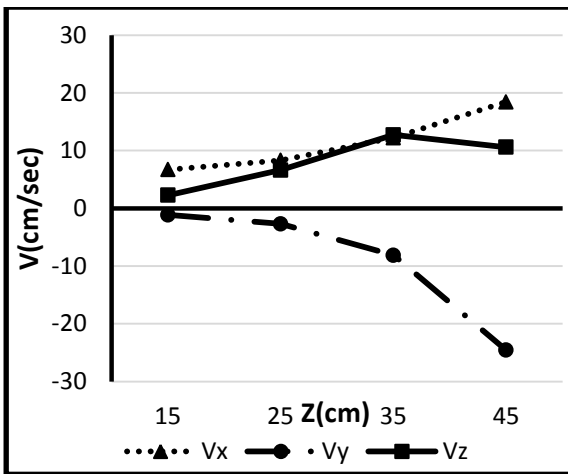


Fig. 9: V versus Z (Pt. 10 Small Model)

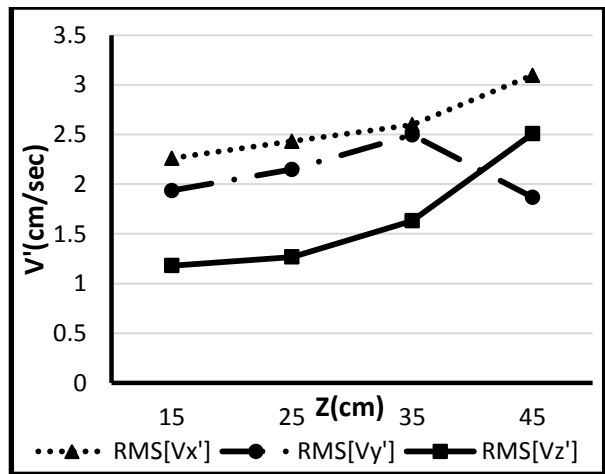


Fig. 12: V' versus Z (Pt. 10 Small Model)

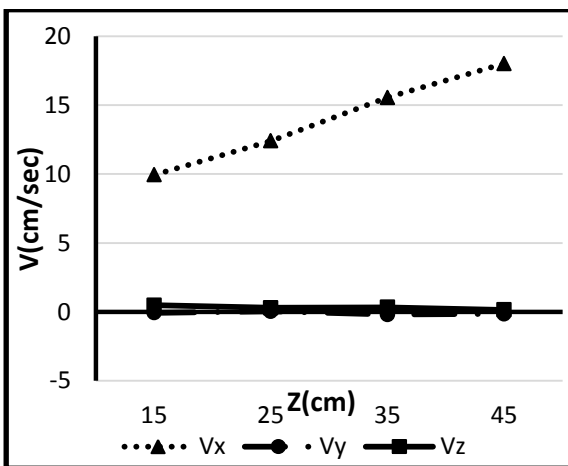


Fig. 10: V versus Z (Pt. 16 Small Model)

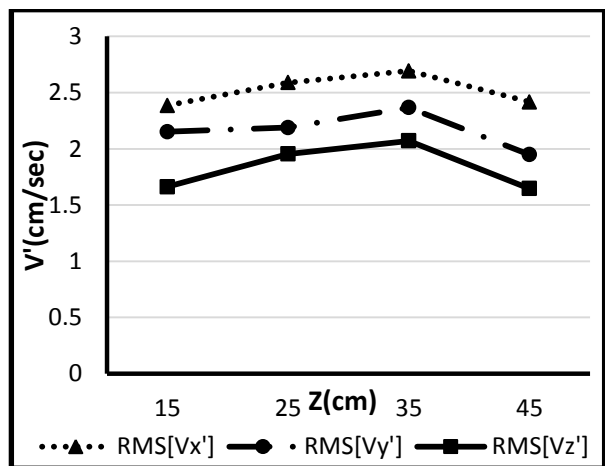


Fig. 13: V' versus Z (Pt. 16 Small Model)



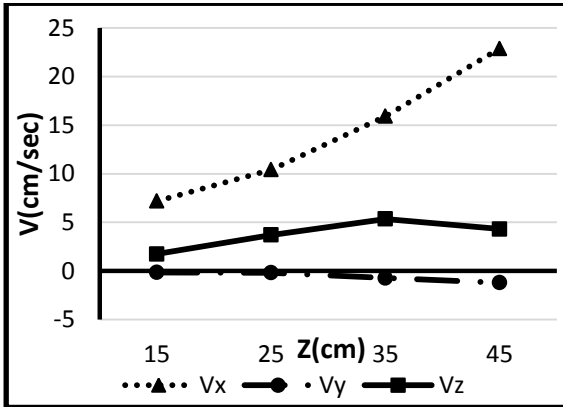


Fig.11: V versus Z (Pt. 17 Small Model)

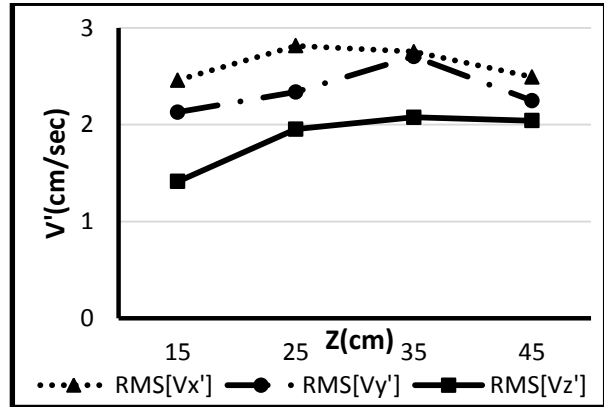


Fig.14:  $V'$  versus Z (Pt. 17 Small Model)

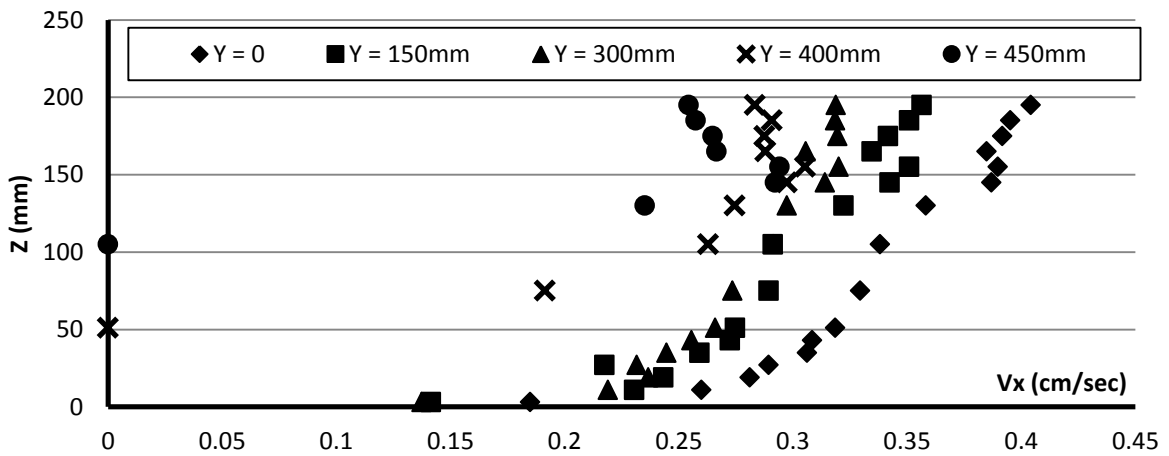


Fig.15: Velocity Distribution for Totally Open Channel Model

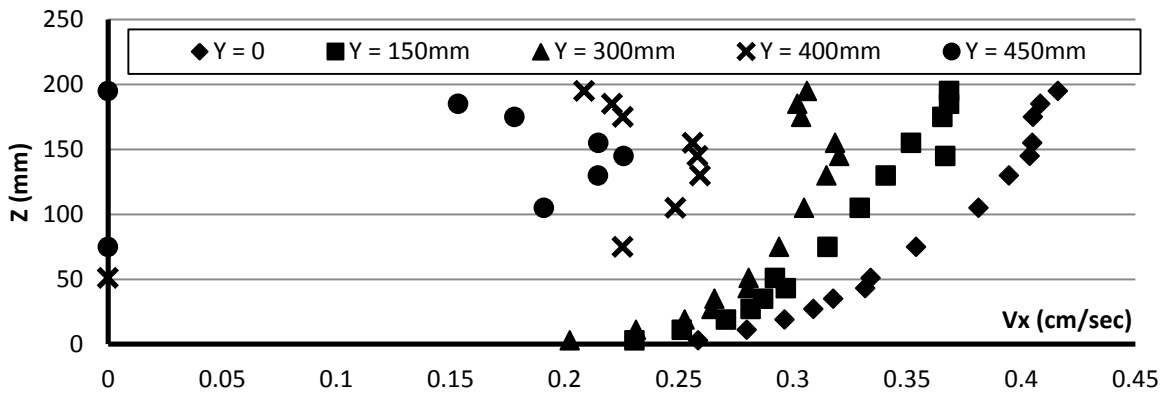


Fig.16: Velocity Distribution for Partially Covered Open Channel Model

This is due to the small decrease in cross sectional area of the partially covered model that required more velocity to pass the same discharge. It is clear that the new MatLab code is capable of post-processing data of new versions of ADV with file extension \*.ntk and \*.vno.

### SUMMARY AND CONCLUSIONS

Two techniques were adopted to post-process the ADV data; velocity and turbulence distributions. The first technique is WinADV software to post-process data of old

manually moved ADV devices with file extension \*.adv. The second is new designed MatLab code for data of new versions automatically moved ADV devices with file extension \*.ntk and \*.vno. The first technique was applied to post-process the ADV data of flow field upstream two models of box inlet spillway. The second technique was applied to the ADV data of two models of open channel trapezoidal flow. Hydraulic discussion using curves and hydraulic principles showed that the two techniques are capable to be used in ADV data post-processing depending on the type of ADV and output data file.

## NOTATION

W	Model width (L)	Y	Transverse distance (L)
L <sub>1</sub> , L <sub>2</sub>	Model length (L)	V <sub>x</sub> , V <sub>y</sub> , V <sub>z</sub>	Components of velocity (LT <sup>-1</sup> )
Z	Vertical distance (L)	V' <sub>x</sub> , V' <sub>y</sub> , V' <sub>z</sub>	Components of turbulence (LT <sup>-1</sup> )

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