Acoustic Doppler Velocity Meters in Complex Flow Conditions

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1. Introduction

The application of Acoustic Doppler Velocity Meters (ADVM) have expanded into a diverse range of technical fields within hydrology, water engineering and coastal engineering. Some of the key technical fields where ADVM's technology are implemented, are surface water runoff, flood management, storm water runoff, water distribution and sediment transport.

The site requirements for ADVM's is a vital aspect for efficient operation of the technology and this poster highlights the requirements at various hydraulic structures and what the impacts will be on the ADVM operation and accuracy of velocity and stage measurements. The hydraulic structures that will be discussed in this poster consist of channels, culverts, bridges and pipes.

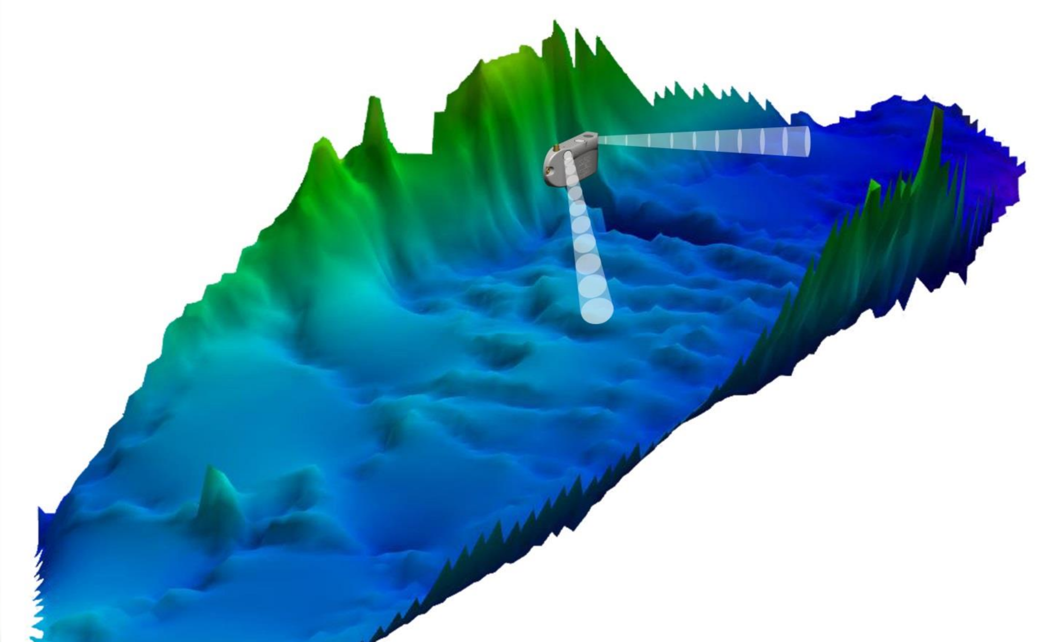


Figure 1: HydroSurveyor survey of SonTek-SL 1500 measurement site

2. Velocity Measurements

The SonTek ADVM's available for velocity measurements are grouped under Side Looking (SonTek-SL) instruments for measurements from river banks, bridge piers and artificial canals and the Up Looking (SonTek-IQ) for measurements in culverts, storm water pipes and pressure pipes. SonTek ADVM's are capable in operating in wide range of flow conditions with the ability to perform discharge calculations in both the Index Velocity or Theoretical Flow methods.

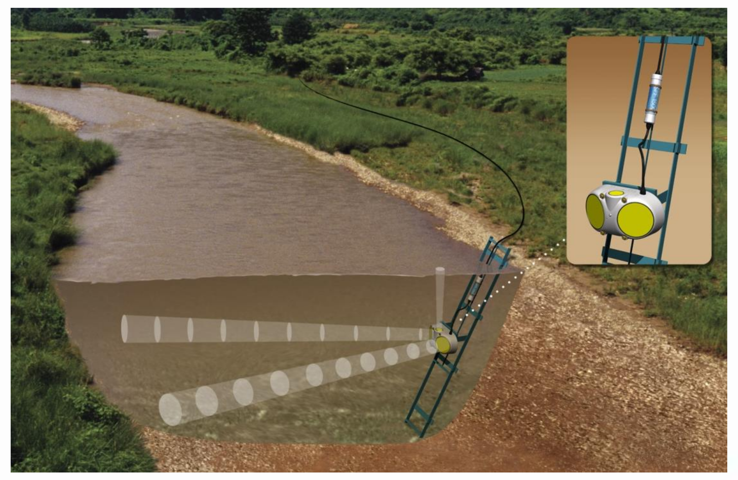


Figure 2: SonTek-SL measurement principle is based on two acoustic beams each slanted at 25° off the instrument axis. The system measures velocity in a horizontal profile that is divided into multiple cells based on the user configuration.

Figure 3: SonTek -IQ measurement principle is based on upstream and downstream acoustic beams along the axis each slanted at 25° off the vertical and two skew beams. The system makes use of SmartPulseHD that adapts the profiling technique, cell size and number of cells based on the flow conditions and water depth.

3. Hydraulic Characteristics

Site requirements are fundamental for the effective operation of ADVM instruments and the development of accurate discharge based on measured velocity. The site requirements for ADVM instruments must comply with the same hydraulic requirements when selecting a monitoring site for developing a stage-discharge relationship, designing an artificial gauging weir or where developed pipe flow conditions are present. It can be said that the hydraulic requirements are even more stringent because there exist a direct relationship between the flow conditions at the monitoring site and the measured velocity.

Site Requirements

- **Steady Uniform** flow conditions
- **Subcritical** flow
- **Drawdown zone** at controls should be avoided
- **Straight length** (10 times section width) of channel with uniform cross-section and slope
- Uniform **velocity distribution** over the width of the cross-section
- Approach velocities with **Froude number** ≈ 0.5
- Flow in the stream should be **confined** to a single well-defined channel
- Wide flood plains and or secondary channels should be **avoided**
- Controls, bends and steep slopes should be located **>10 times** the section width upstream due to possible that can create turbulent flow
- **Roughness** of the riverbed and banks must be investigated for affecting velocity distribution
- Avoid prominent **obstructions** in a pool that can affect the velocity pattern.
- Discharge **sensitivity** towards the channel section
- **Aquatic plants**
- **Sediment** deposition and scouring
- Access to the site during **flood events** is important.

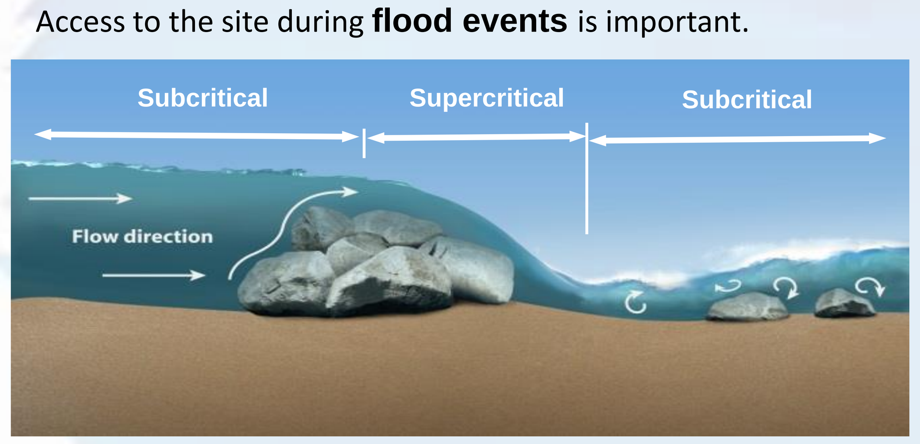
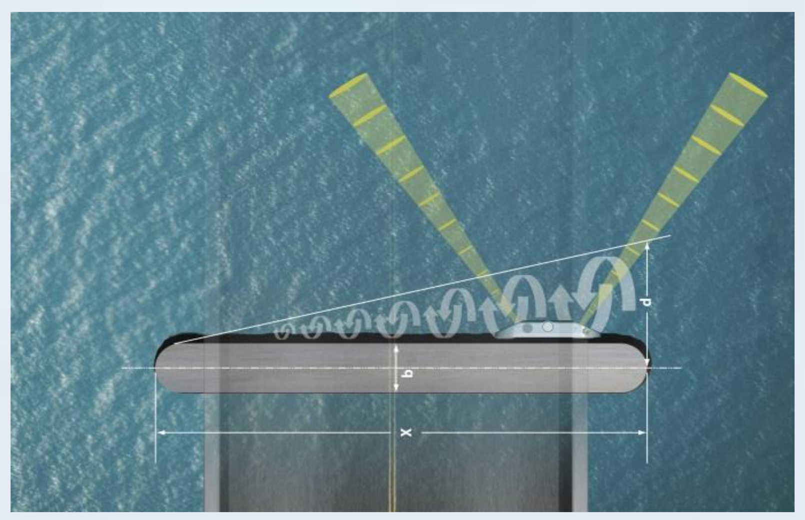


Figure 4: Flow Classification

Hydraulic Conditions Impacting Measurements

Figure 5: Flow turbulence created by the bridge piers or embankment can significantly impact the ADVM measurements. It is recommended that the minimum blanking distance is based on the following formula that incorporates the bridge pier thickness, form factor and distance from upstream face of the bridge pier to the ADVM.

$$d = c \times (b \times x)^{0.5}$$



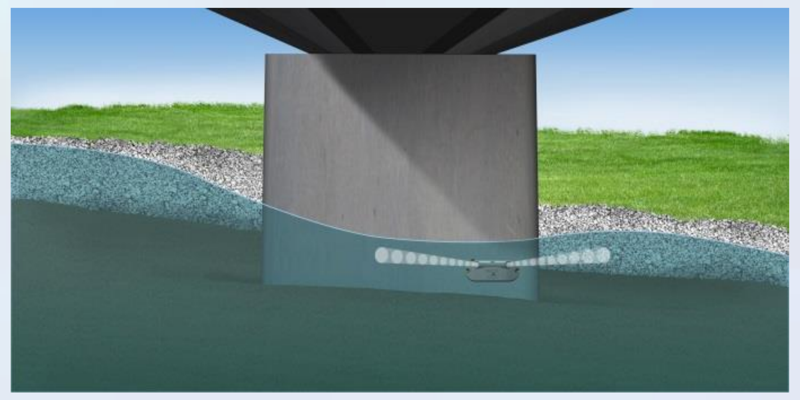
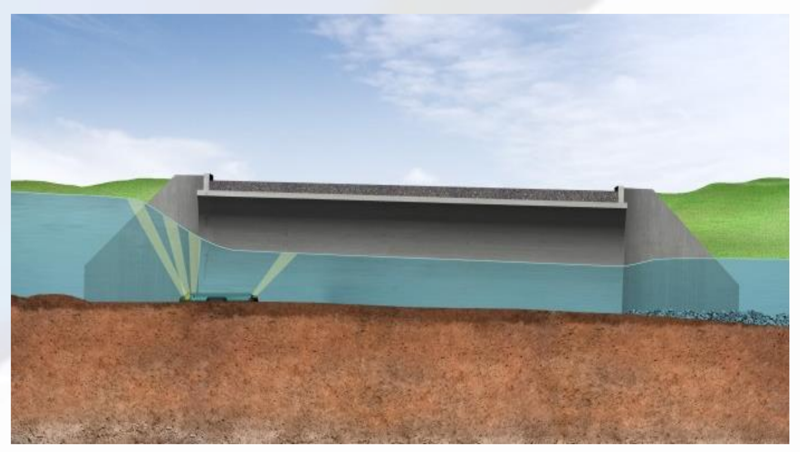


Figure 6: Supercritical flow conditions or multiple flow regimes within the affective measurement volume of the instrument can significantly impact the ADVM measurements and it is advised that these situations be avoided as far as possible.

Figure 7: Drawdown and change in flow regime can significantly affect the ADVM measurement. It is advised that the **critical flow** zone at the inlet or outlet of culverts be avoided as far as possible.



References

- Wessels[1], P., and Rooseboom[2], A., 2007, Flow Gauging Structures in South-African Rivers, [1]Depratment of Water Affairs, [2]University of Stellenbosch, South Africa.
- Levesque, V.A., and Oberg, K.A., 2012, Computing discharge using the index velocity method: U.S. Geological Survey Techniques and Methods 3–A23, 13p.
- Rantz, S.E., 1982, Measurement of Stage and Discharge; chap. 9 - Indirect Determination of Peak Discharge: U.S. Geological Survey WSP 2175, 282p.

4. Case Studies of Impacts on ADVM Measurements

SL Boundary Effects

Boundary effects can bias the velocity measurements low and the user needs to make sure during the site selection and instrument installation process that the ADVM measurement is not affected by any boundary influences.

The boundaries that can impact on ADVM measurements are, channel bed, opposite channel bank, water surface and obstructions in the channel. The boundary effects can be prevented by applying some practical applications during instrument installation,

- Aspect ratio (range / distance) is in the order of 15–20 and is dependent on site conditions.
- Cell end is 10% of channel width from opposite bank

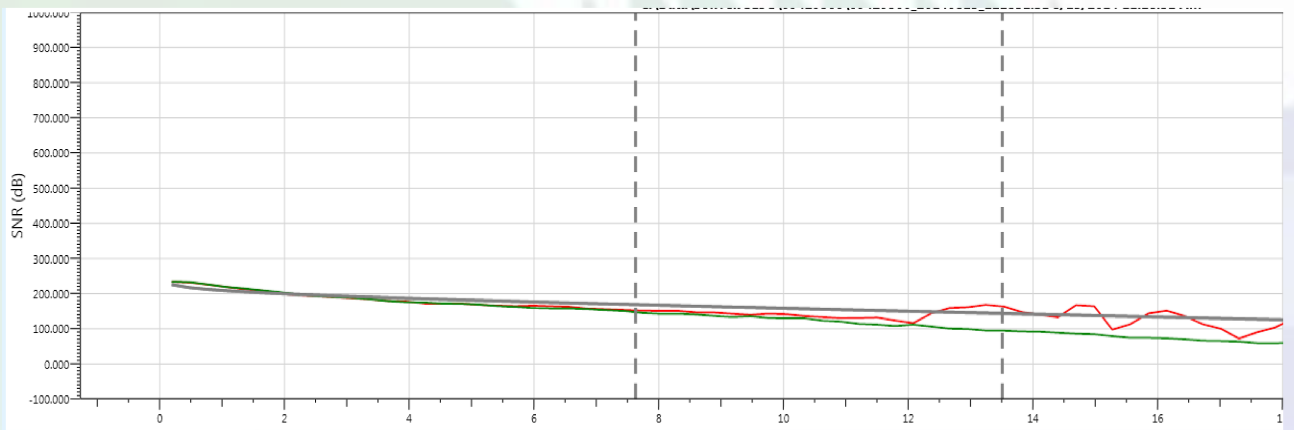


Figure 9: Diagnostic Data

Figure 8: SonTek-SL1500 Installation

The SNR data indicate that the water surface or channel bed affecting the measurement at about 12m from the instrument.

Bathymetry survey (Figure 1) was performed with HydroSurveyor across the affective measurement volume to determine if there were any obstructions in the channel that could influence the measurements. The survey highlights some anomalies that can impact the measurements, however the operational water level limited the adjustment of the instrument and as a result the index velocity range will be limited to 12m.

SL Velocity Distribution

The velocity distribution can vary significantly throughout the discharge extent and the site reconnaissance need to incorporate the following criteria during the process,

- Velocity distribution throughout discharge extent
- Stage Discharge sensitivity of section

The plots show the magnitude and direction of each individual cell velocity during high and low flow conditions. The measured cell velocities during medium to high flow conditions shows that the velocity distribution across the section is well distributed and uniform.

The low flow conditions are the exact opposite with skew flow occurring in most of the section and backflow present on the left bank. The velocity distribution during low flow conditions is a result of a combination of the following site related aspects,

- Wide measurement section
- Deep upstream pool
- Stage discharge relationship is not sensitive.

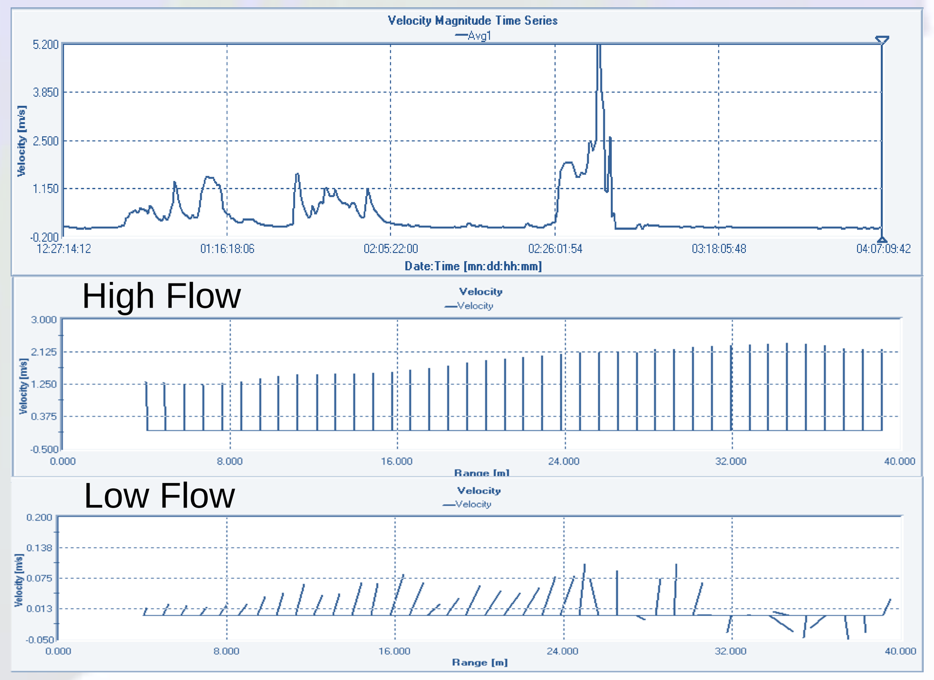


Figure 10: Velocity Magnitude plot

IQ Beam Burial

Beam burials are more applicable to bottom mounted ADVM's, more specifically the SonTek-IQ series. Beam burials occur when one or all beams are buried under sediment and the instrument is unable to operate sufficiently under these conditions.

The SNR plot is a good indicator to verify if beam burial has occurred. If there is a consistent downward trend in the SNR plot towards zero for one or all beams, it indicates that beam burial has occurred.

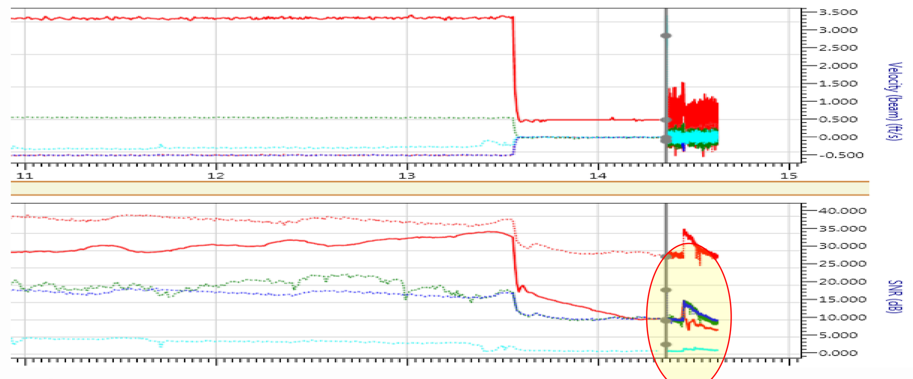


Figure 11: SNR Plot showing beam burial

IQ Alignment with Cross Section

The cross section geometry and the instrument position in relation to the cross section need to be accurately determined. The exact measurements as surveyed must be entered in the SonTek-IQ software in the "Channel Shape" section.

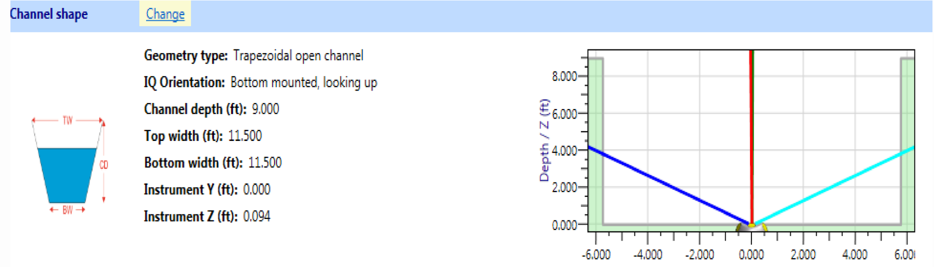


Figure 12: IQ Channel Shape setup page

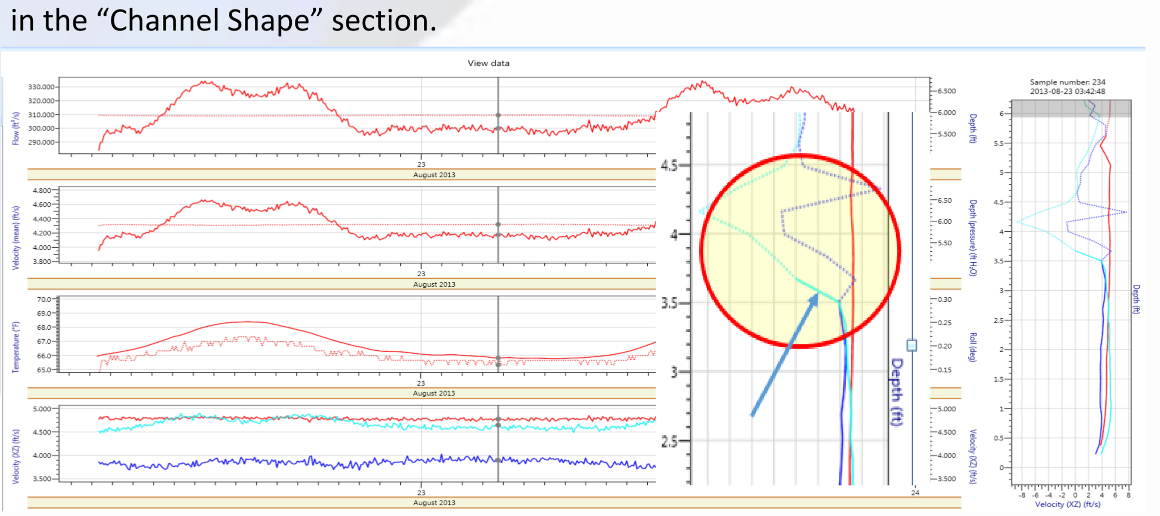


Figure 13: IQ Velocity Profile of Skew Beams

The velocity profile of the skew beams in this scenario shows that there is reduction in velocity at the last measured cell at each of the skew beams. The beams are hitting the walls of the channel on both banks and as a result the velocity is biased low.

Jet Flow Conditions in Pipes

Jet flow occurs in pipes when the conduit flow area is reduced in combination with hydraulic pressure available. The extent of jet flow is dependent on the ratio of reduced flow area and hydraulic pressure. Jet flow can be generated by the following pipe fittings,

- Valves
- Pipe constrictions

The instrument is positioned in a pipe network downstream of balancing tank at a distance of 15 x diameter. The graphical illustrations show the velocity distribution in the pipe for 25% and 75% valve opening. The 25% valve opening clearly shows that the maximum velocity occurs about 1/3 from the bottom of the pipe. The 75% valve opening shows a better velocity distribution and start to resemble the theoretical velocity profile for turbulent flow conditions in pipes.

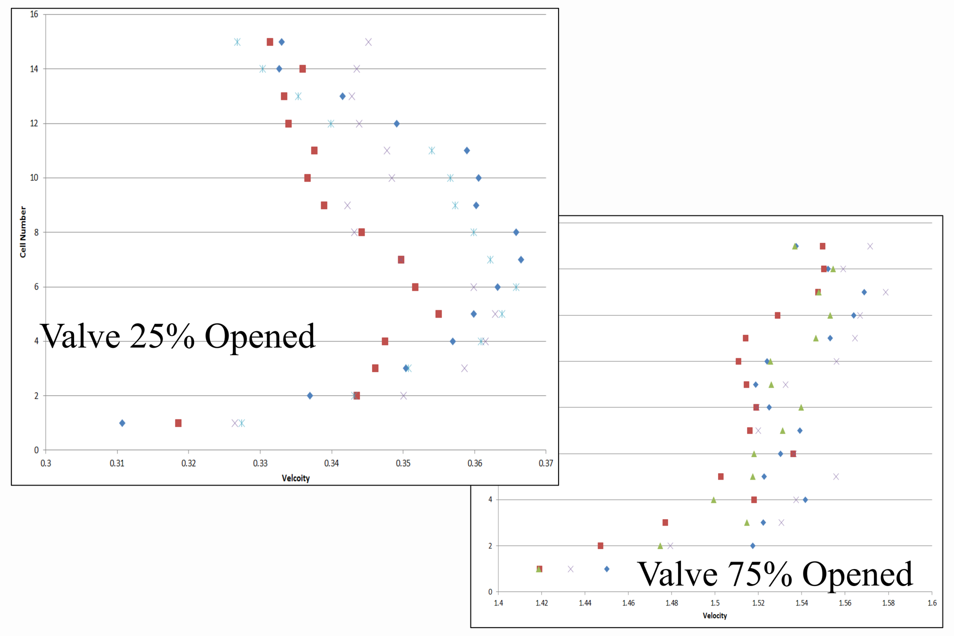


Figure 14: IQ Velocity Profile of Centre Beams