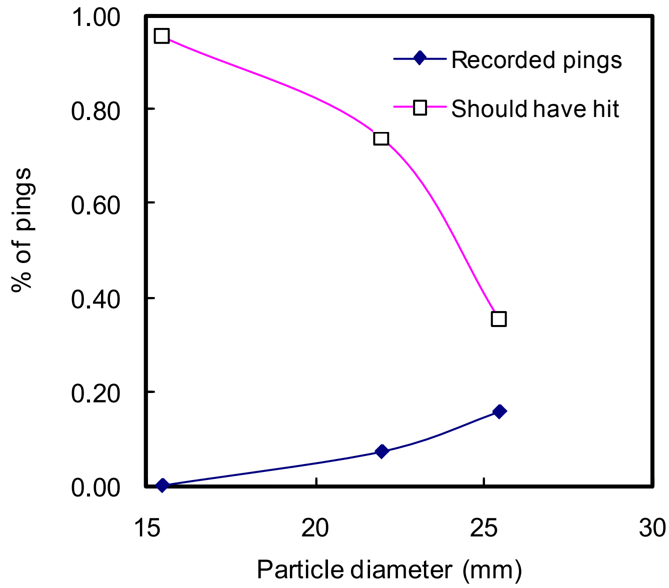

Figure 10. Comparison between theoretical and recorded pings.

This trend in figure 10 can partly be explained by changes in flow due to the presence of the cylinder. As the flow approaches the cylinder with an angle of attack $\alpha = 0^o$, as defined in figure 11 where z is in the vertical direction, U(y) diminishes considerably and close to the bed a flow reversal is established (Graf and Yulistiyanto, 1998) (figure11). Flow going around the cylinder undergoes an acceleration and as $\alpha \rightarrow 45^o$, V(y), the velocity in the transverse direction, increases and reaches values of the same order of magnitude as U(y) (Graf and Yulistiyanto, 1998). In front of the cylinder the separation point is influenced by the negative W(y) component, where W(y) is the velocity in the vertical plane. Through experiments for air flow around cylinders, Belik (1973), found the following relation (eq. 4) to be true for $2.2\times10^5 > Re_\delta > 3.6x10^4$.

$$\frac{a}{D} = 0.57(2\times10^{-5}\times \mathrm{Re}_\delta)^{0.19} \qquad (10)$$

where, a is the distance along the bed from the cylinder to the point of separation, D is the diameter of the cylinder, and $Re_\delta = U_e\delta/\nu$. For open channel flow, δ can be taken as the depth of flow h. Graf and Yulistiyanto (1998) applied equation (10) to a combination of air flow and free surface flow data in the range of $11.5x10^5 > Re_h > 1.6x10^3$ and found it to be valid. Hence, as Re_h increases, so does the distance of the separation point form the cylinder at a position of $\alpha = 0^o$. The values of Re_h for the present study fell within the range examined by Graf and Yulistiyanto (1998).

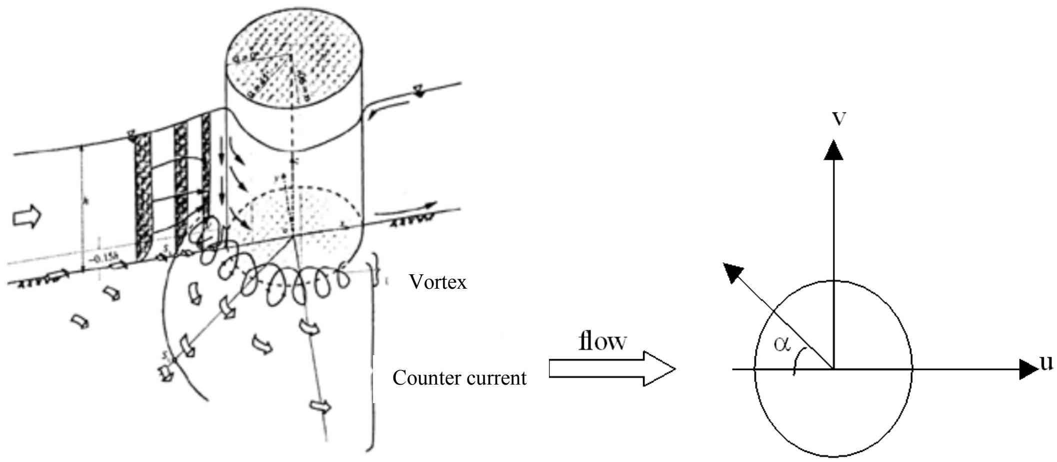

Figure 11. Flow around a cylinder (after Graf and Yulistiyanto, 1998).

This flow reversal in front of the cylinder can have an effect on the particles moving as bedload. It was observed during test with the smallest size, 15.9 mm (5/8 in), that before they hit the cylinder, particles come to rest and cluster (fig. 12). Formation of these clusters would greatly reduce the GTS's ability to accurately measure bedload.

Figure 12. Clustering of particles.

5. CONCLUSIONS

The development of the GTS is a necessary step to better understand sediment transport in gravel bed channels, especially for low flow conditions. Its ability to make unattended local measurements, record data over long periods of time, capture the larger size fractions, and the ease of movement are all advantages the GTS has over the other current techniques. Testing on the prototype model showed that the ability of the GTS to make accurate measurements increases as particle size increases. The presence of the cylinder in the flow can have a large effect on the smaller sized particles and cause them to follow the streamlines around the cylinder rather than impacting it. Further testing needs to be conducted to find particle velocity under varying flow conditions and relate its momentum to the detection rate of the GTS. The prototype GTS is only in its first stages. Further development of the GTS piezoelectric vibration sensor will allow for an improved correlation between the momentum of a particle and the acoustic output signal. This will allow the GTS to record a particles momentum to account for non-uniformity in the bed material. In addition, a modification of the cylindrical shape of the GTS to a rhomboid shape in order to minimize flow reversal will probably improve the effectiveness of the instrument (figure 13).

Figure 13. Proposed modification of the GTS shape.

Finally, the developed particle velocity equations have great potential for bedload applications and the instantaneous particle velocity equation can be used to calibrate the GTS. Also, the virtual velocity relation can be used to develop a bedload transport equation. The study showed that the virtual velocity is about 5 times less in magnitude than the flow velocity. The size of the entrained particle versus the size of the bed is a key factor in the resting period that affects the overall movement of a particle. Future work on the virtual velocity and the excess shear correction is warranted.

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