Gravity wave effects on the calibration uncertainty of hydrometric current meters

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Abstract

Hydrometric current meters are usually calibrated in tow tanks, like the calibration facility from METAS in Ittigen, Switzerland. The uncertainty budget for this installation yields a value of 0.04 % for the lowest achievable uncertainty in velocity of the towing carriage. This paper presents some results obtained from observation with Acoustic Doppler Current Meters (ADCM) on the residual currents generated from the towing of the current meters through the tank which generate surface gravity waves. Their potential impact on the calibration uncertainty is discussed and the effect of various waiting times on repeatability is shown.

1. Introduction

Hydrometric current meters are used to measure the velocity distribution in open channels and are usually calibrated over a range of speeds by towing them through still water in a tow tank, following the International Standard ISO 3455 [1] for instance. *Calibration of a current meter means experimental determination of the relationship between liquid velocity and either the rate of revolution of the rotating element or the velocity directly indicated by the current meter*, as quoted in [1].

The uncertainty budget for the calibration facility in Ittigen, Switzerland, yields a value of 0.04 % for the velocity of the towing carriage in the range from 0.02 m/s to 10 m/s and represents the lowest achievable uncertainty assuming a perfect current meter (i.e. no contribution from the current meter) and perfectly still water. The uncertainties quoted in the calibration certificates issued by the calibration facility apply to the actual measurements of the number of revolutions per second of the impeller at a certain towing speed and can strongly vary depending on the quality of the current meter.

The successive measurements through the tank perturb the water and generate residual currents which can interfere and increase the velocity noise of the current meter or add a systematic error. To limit this noise, waiting times between successive runs are introduced to allow for the decay or the damping of these residual currents. The time needed for the water to still depends on several factors like the dimensions of the tank, the previous test velocity and the type of suspension equipment immersed in the water. Damping or stilling devices can reduce the reflection of disturbances in the water by the end walls of the tank.

This paper will present results obtained from observations with Acoustic Doppler Current Meters (ADCM) on the residual currents generated from the towing of current meters through the tank and their effects on the uncertainty using mechanical hydrometric current meters. All measurements have been performed in the tow tank, which has a length L of 140 m, a width of 4 m and a depth of 2 m, of the calibration facility in Ittigen between the end of 2011 and April 2012. The water level H in the tank is around 1.7 m.

2. Water motion and surface gravity waves

The assumption that water in a tow tank is perfectly still is not valid. There are always residual velocity fields from previous disturbances or other convection effects. Ref [2] quotes values of a few mm/s for typical convection velocities in an undisturbed tank and are therefore hardly an issue for mechanical current meters, which have start-up speeds of 2 cm/s at least.

Current meters are attached through rods to the towing vehicle and when dragged through the water will push on the water and generate a wake and a propagating wave. The wave motion that occurs at the free surface of the water, where gravity plays the role of the restoring force, is called a surface gravity wave and its dispersion relation (relation between frequency and wavelength) can be found in textbooks [3] and reads

$$\omega = \sqrt{gk \tanh(kH)} \qquad (1)$$

where $\omega = 2\pi\nu$ is the circular frequency, g the earth's gravitational acceleration, $k = \frac{2\pi}{\lambda}$ the wavenumber, λ the wavelength and H the depth of the water. Depending on the ratio between the wavelength λ of the wave and the depth H of the water, interesting simplifications result

$$\frac{H}{\lambda} \ll 1 \; (shallow\; water) \qquad (2)$$

$$\frac{H}{\lambda} \gg 1 \; (deep\; water) \qquad (3)$$

For shallow water, we can approximate $\tanh(\frac{2\pi H}{\lambda}) \approx \frac{2\pi H}{\lambda}$, which yields the following relations for the frequency ν and the speed c of the wave

$$\nu = \frac{1}{\lambda}\sqrt{gH} \qquad (4)$$

$$c = \sqrt{gH}, c = \lambda\nu \qquad (5)$$

A limited body of water like a tow tank forms standing waves by reflection from the walls and a standing oscillation in such a case is called a *seiche*. Only certain wavelengths and frequencies are allowed by the boundary conditions from the tank and are given by

$$\lambda = \frac{2L}{n+1} \quad (6)$$

where L is the length of the tow tank and n denotes the mode of the wave.

A numerical application to the METAS tow tank (L = 140 m, H = 1.7 m) yields the following values:

- λ_0 = 280 m for n = 0, λ_1 = 140 m for n = 1, , λ_2 = 93 m for n = 2
- H/λ_0 = 6.1e-3 << 1, the shallow water approximation can be used
- $c = \sqrt{gH}$ = 4.1 m/s (with g = 10 m/s^2)
- ν_0 = 0.0147 Hz
- $T = 1/\nu_0$ = 67.9 s

It should be noted that in shallow water, the particle orbits due to the wave are described by ellipses with their major axis oriented along the direction of propagation of the wave. In deep water, the particle orbits are circles as can be seen in Figure 1.

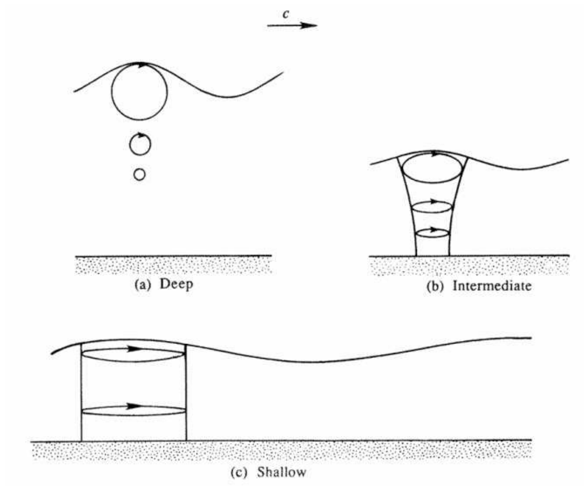


Figure 1: Particle orbits of wave motion in deep, intermediate and shallow water, taken from [3].

3. Water motion generation and observation method

Water disturbances have been generated by towing three of our standard mounting rods of dimensions 75 mm x 35 mm through the tank, as can be seen in Figure 2 where one also recognises the seeding material in the water which is used to reflect the sound emitted by the ADCM.

Figure 2: The towing vehicle with the 3 mounting rods.

To observe the residual current generated by the towing of the three rods, we used as ADCM a FlowTracker Handheld-ADV (Acoustic Doppler Velocitymeter), see Figure 3, from SonTek/YSI (USA) equipped with a 3D probe to record the water velocities in the 3 spatial directions. All data were stored on the device and later downloaded to a PC for additional processing.

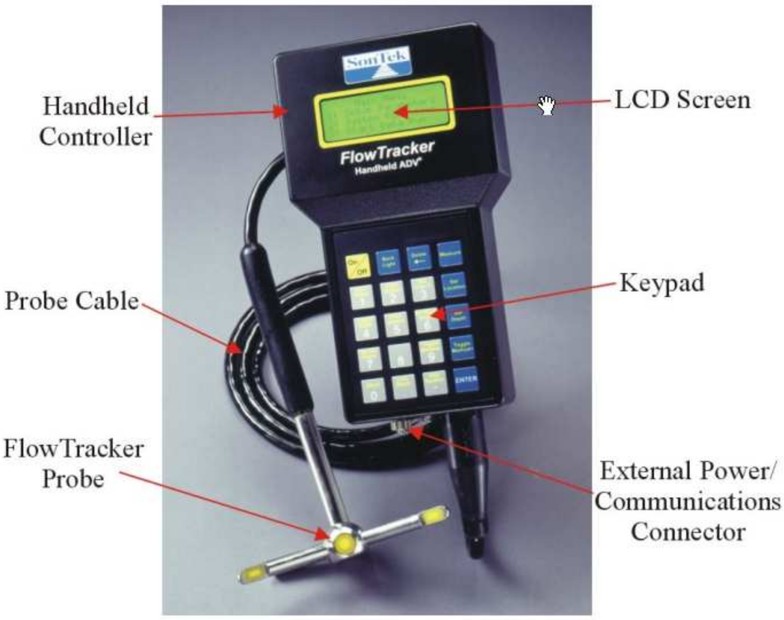


Figure 3: FlowTracker with 2D Side Looking Probe, taken from [4]

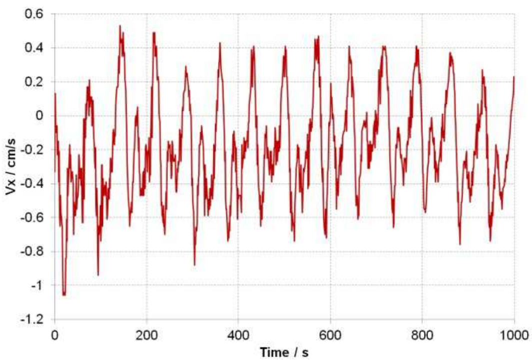
The FlowTracker records a velocity sample and quality control data (Signal to Noise ratio) every second based on 10 pings. It can measure water velocities from 0.01 cm/s to 4.5 m/s with an accuracy of 1% and is especially well suited for low-flow applications [4]. The maximum recording time is limited to 1000 seconds.

Runs have been performed at towing speeds of 1 m/s, 2.5 m/s and 5 m/s. After each forward run, the towing vehicle returned to its starting position with the mounting bars retracted from the water so as to ensure maximum measurability of the wave. The standard calibration procedure from METAS asks for the mounting rods to be still immersed for the backward journey of the vehicle which occurs at a limited speed of 0.7 m/s. This situation has also been analysed and no obvious change with or without immersed rods has been observed. The FlowTracker probe was then mounted on the rod in the middle and the vehicle was moved to a position 52 m along the tank with retracted rods. At this point, the vehicle was brought to a stop and the FlowTracker probe was placed in the water at a depth of 30 cm to measure the residual water velocity. This depth corresponds to the mounting position of current meters during calibrations.

The time laps between disturbing the water, mounting and placing the FlowTracker in the water was about 3 minutes. We could only observe by eye that the generated wake decayed rapidly during this time laps.

4. Results of water motion observation

The velocity of the residual current along the towing direction, after disturbing the water with a run at 1 m/s, is shown in the left part of Figure 4. The measuring time is 1000 seconds. One observes an oscillating velocity of amplitude 0.5 cm/s, consistent with the elliptical path of the particle orbits and typical for seiches, which take a long time to dissipate. The associated Fourier spectrum of this oscillation is shown in the right part of Figure 4 where one can clearly identify the 3 first modes of the surface gravity wave in excellent agreement with the numerical estimation presented in Section 2.



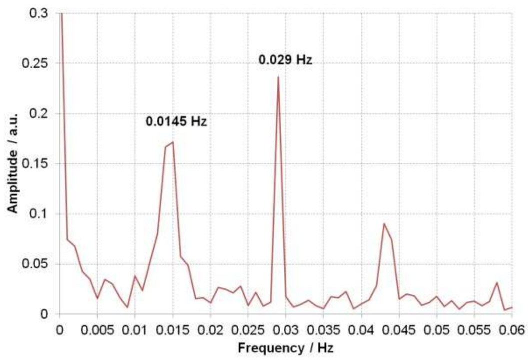


Figure 4: Left) Residual velocity after a run at 1 m/s. Right) Associated Fourier spectrum from the graph on the left.

Similar results have been obtained for the other towing speeds. The results for 5 m/s are shown in Figure 5.

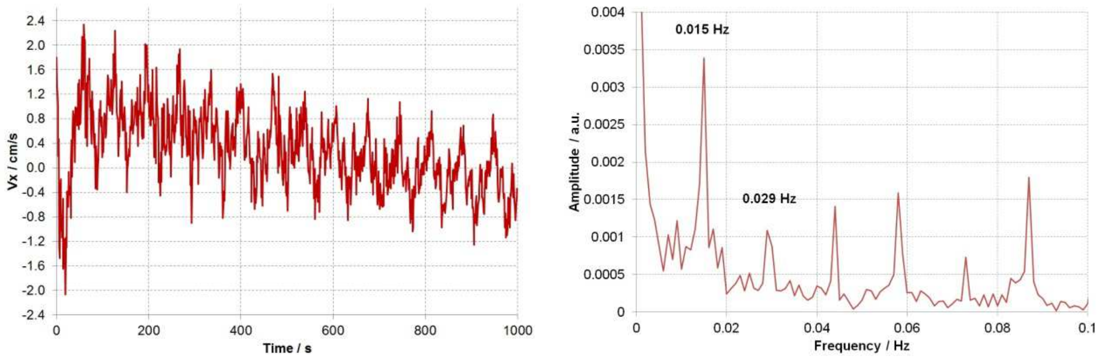


Figure 5: Left) Residual velocity after a run at 5 m/s. Right) Associated Fourier spectrum from the graph on the left.

One observes the same kind of oscillations at the same frequencies. There is another visible damping, most probably due to the still present wake from the higher towing speed. The amplitude of the oscillation scales apparently with towing speed, reaching 1.2 cm/s in this case.

5. Attempt to mitigate the water motion

We tried a simple and crude trick to dampen the surface wave generated by the towing rods by placing so called wave-absorbing lane lines (we called them wave-breakers) at both ends of the tow tank, like shown in Figure 6. Such devices are used in swimming pools to separate the lanes and to minimise the turbulences for the swimmers.

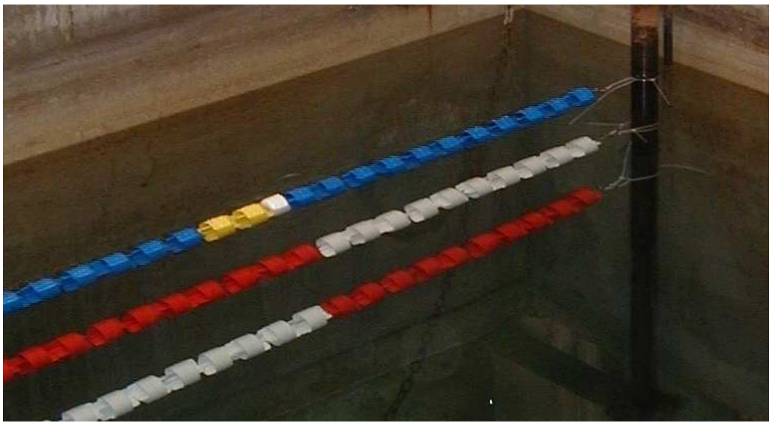


Figure 6: Wave-breakers mounted at both ends of the tow tank.

We spanned 3 rows of wave-breakers, on cables across the width of the tank, each separated vertically 30 cm from another, the first one being half immersed in the water. The residual velocity after disturbing the water at 1 m/s with and without wave-breakers and their associated Fourier spectra are shown in Figure 7.

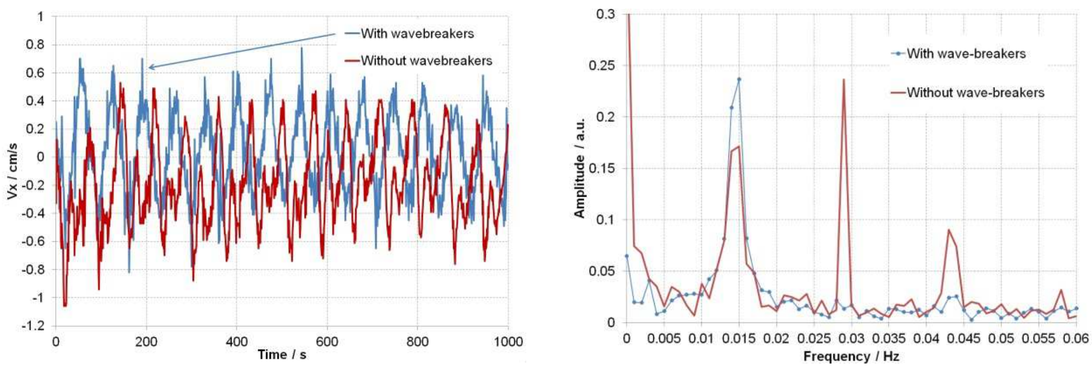


Figure 7: Left) Residual velocity after a run at 1 m/s with and without wave-breakers. Right) Associated Fourier spectra from the graph on the left.

No clear dampening effect can be deduced from the velocity plot. The frequency spectra however indicate that the wave-breakers act like a low-pass filter and attenuate the higher order modes of the surface wave.

These results indicate that our attempt to mitigate water motion with our wave-breakers was not successful and that a more complex water-stilling device is needed. The US Hydrologic Instrumentation Facility use waste water trickling filter media placed at both ends of the tank, as well as wave-breakers placed on the side walls of the tank to attenuate the wake [5].

6. Influence on measurement uncertainty

The impact of the observed surface wave on the uncertainty of the measurement has to be analysed. As can be seen in Figure 4, an oscillating velocity with amplitude 0.5 cm/s and period 67 seconds along the towing direction is still present following a run at 1 m/s after more than 15 minutes. This means that depending on when the next run starts and its duration, the current from the surface wave generate by the previous towing will be acting either along and/or against the direction of motion of the impeller during the towing and thus introducing an unknown speed contribution to the measurement.

For small towing speeds, where the current meter is towed during a time larger or similar than the oscillation period of the surface wave, the contribution from the surface wave will average over time and increase the standard deviation of the measurement. If the run lasts less than half the period of the oscillation, the contribution from the surface wave will depend on the phase relation between the start of the run and the surface wave.

At the present time, it is difficult to put hard figures on the contribution from surface waves to the measurement uncertainty because we measured the surface wave in a stationary mode while the calibration process produces a superposition between the standing surface wave and the surface wave generated by the current run. It is quite safe to say that the contribution to a 1 m/s run must be between 0 cm/s and 0.5 cm/s, depending on the phase relation between the start of the run and the surface wave. We do not have enough data at the moment. Further measurements are envisioned.

7. Waiting time effects

The waiting time between successive runs are introduced to allow for damping of residual currents. At the calibration facility in Ittigen, typical waiting times used during calibration services by METAS are 10 minutes at least for runs between 0.3 m/s and 1 m/s and 25 minutes at least for runs between 1 m/s and 5 m/s.

To study the effect of waiting times on reproducibility of the outcome of the calibration, we have performed several successive runs at a towing speed of 2.5 m/s with 2 mounted Seba F1 mechanical current meters. Each run lasts 10 seconds, well below the period of the surface wave. Before each set of runs, both current meters have been cleaned and oiled. First 10 successive runs, each separated by the standard waiting time of 25 minutes have been performed, followed by 50 runs with 5 minutes waiting in between. The mean speed for each set of runs was then determined, which allowed to calculate the relative deviation with respect to the mean speed for both sets of runs shown in Figure 8. The black lines indicate an uncertainty band of ± 0.04 %.

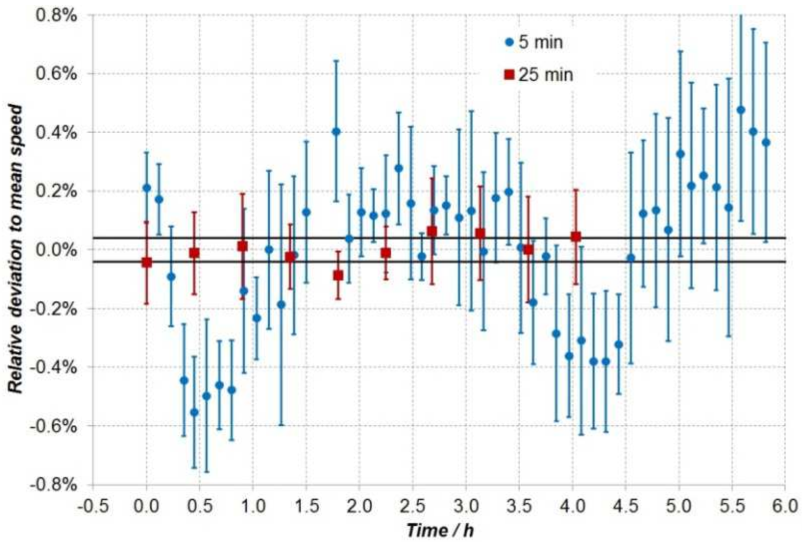


Figure 8: Relative deviation with respect to the mean speed for both sets of runs.

One sees immediately that reproducibility is heavily influenced by the waiting time between successive runs. When waiting the standard 25 minutes, the reproducibility is very good, well below 0.1 %. When reducing the waiting time between runs to 5 minutes, water disturbances limit the reproducibility to ± 0.5% which corresponds to an uncertainty of 1.25 cm/s for a towing speed of 2.5 m/s. This value of 1.25 cm/s is actually quite close to the amplitude of the surface wave one would expect to be generated when towing at 2.5 m/s.

8. Conclusions & outlook

The calibration of current meters in tow tanks is sensitive to residual currents in the water. The operation of towing current meters through the water generates gravity surface waves whose amplitude is related to tow speed and whose period is only related to the tank dimensions. These so-called seiches take a long time to dissipate.

The current from the surface wave introduces an unknown speed contribution to the measurement and adds a systematic uncertainty that depends on the duration of the run and the phase relation between the start of the run and the surface wave. Further measurements are needed to put numbers on the contribution from surface gravity waves.

Waiting times between successive runs allow for the water to still and their proper choices strongly influence the repeatability between measurements. An example showed that the METAS waiting times allow a good reproducibility for successive measurements.

Technical improvements to mitigate unwanted water movements in the tow tank from METAS should be introduced to further increase the accuracy of the calibration facility.

References

[1] International Standard ISO 3455:2007 *Hydrometry – Calibration of current meters in straight open tanks*

[2] F.T. Thwaites and A.J. Williams, *Use of tow tanks to study sensitive current meters*, OCEANS ’97 MTS/IEEE Conference Proceedings vol. 2 1089-1093 (1997)

[3] P.K. Kundu and I.M.Cohen, *Fluid mechanics 4th Edition* (Academic Press, London, 2008)

[4] FlowTracker Handheld ADV Technical Manual, SonTek/YSI, Inc.

[5] K.G. Thibodeaux, Hydrologic Instrumentation Facility, USA, *Private communication*