Improved flow measurement using EM flat probes in mixed flow conditions

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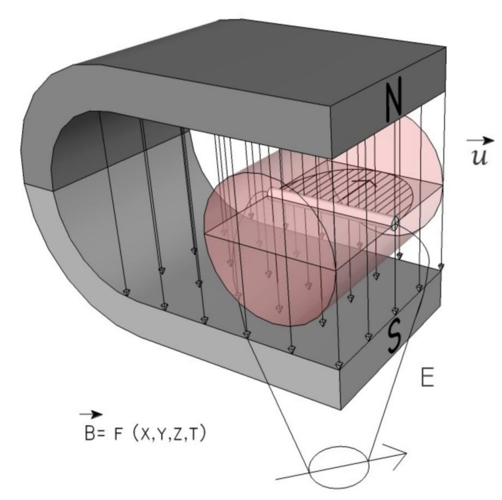
Introduction and Background

Commonly used approach for the flow measurements in sewer systems is velocity-area methods. The velocity sensors often operate with high uncertainty (Hughes et al., 1996) and have to cover wide range of hydraulic conditions including the mixed flow conditions – combination of the pressurized and free surface flows. Uncertainties are related both to the measured parameters and the validity of the applied transformation – how the measured velocity is related to the actual mean velocity (Bonakdari & Zinatizadeh, 2011). In order to reduce the uncertainty, robust velocity sensors are needed (flat EM) and additional site-specific calibration procedure. Concept of its application in the engineering practice example is shown.

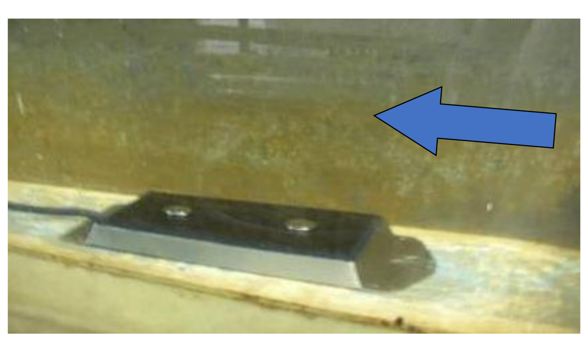
Flat EM sensors for velocity measurement

EM flowmeter's operating principle is based on the Faraday's law: measured signal (induced voltage between the electrodes *E*) is generated by motion of fluid through a transversal magnetic field.



$$E = \int_A \vec{u} \cdot (\vec{B} \times \vec{j}) dA$$

E - induced voltage
$\vec{j}$ - virtual current
$\vec{B}$ - magnetic flux density



The flat EM sensor designed by *Svet Instrumenata* can be used for the free surface and mixed flow conditions. Sensors are **robust**, and **can operate even with thick layer of sand and deposit**.
The sensitivity of the sensor can be described using the relation developed for the full-pipe EM flowmeters (Bevir, 1970).

Site-Specific Calibration procedure

The Site-Specific Calibration (SSC) procedure will simulate real flow conditions in the vicinity of the EM probes, in order to reduce the uncertainties. Each EM sensor is calibrated in towing tank with constant velocity around the probe, different from the local velocity pattern at the measuring position. The CFD is **used to predict the true velocity field** and to calculate the deviation from the field used during the calibration of EM sensor, for all mixed flow conditions, and for each used EM sensor. The proposed SSC procedure consists of the following steps:

1. **Global hydraulic analysis – 1D steady/unsteady mixed flow model (reference)**
2. **Local hydraulic analysis – 3D CFD simulations utilizing URANS turbulence modelling strategy (OpenFOAM)**
3. **Magnetic field analysis – Melexis MLX90393 (example on Fig. 1)**
4. **SSC curve derivation**

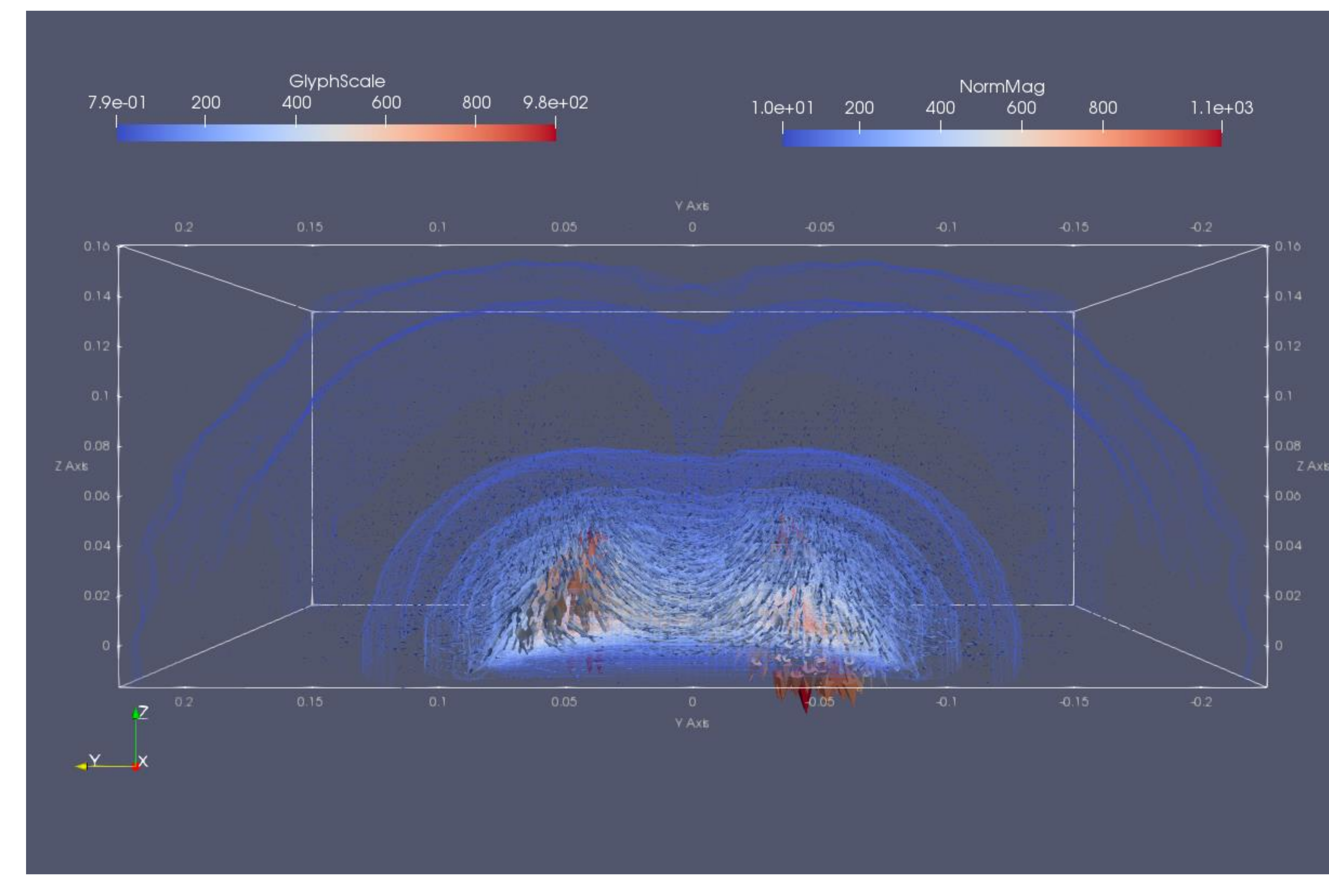


Figure 1. Magnetic field distribution for the FLAT EM 400 (Measured with Melexis MLX90393) – Front view

Figure 2. Entrance to the derivational tunnel

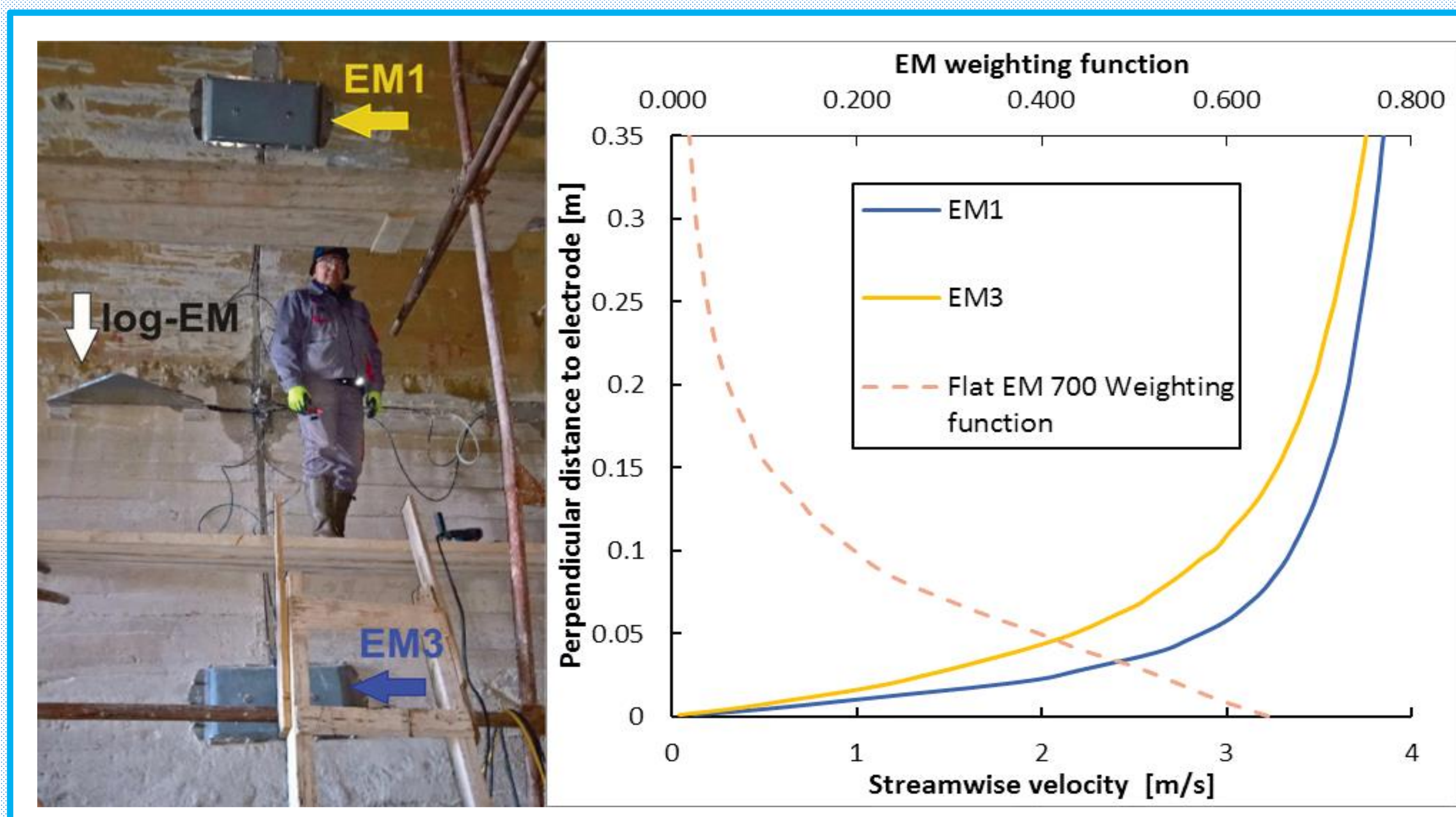


Figure 3. Example application: left) Two flat EM and one log-EM probe on the left side of the derivational tunnel; right) Velocity data obtained from CFD analysis combined with the probes 1D weighting function approximation

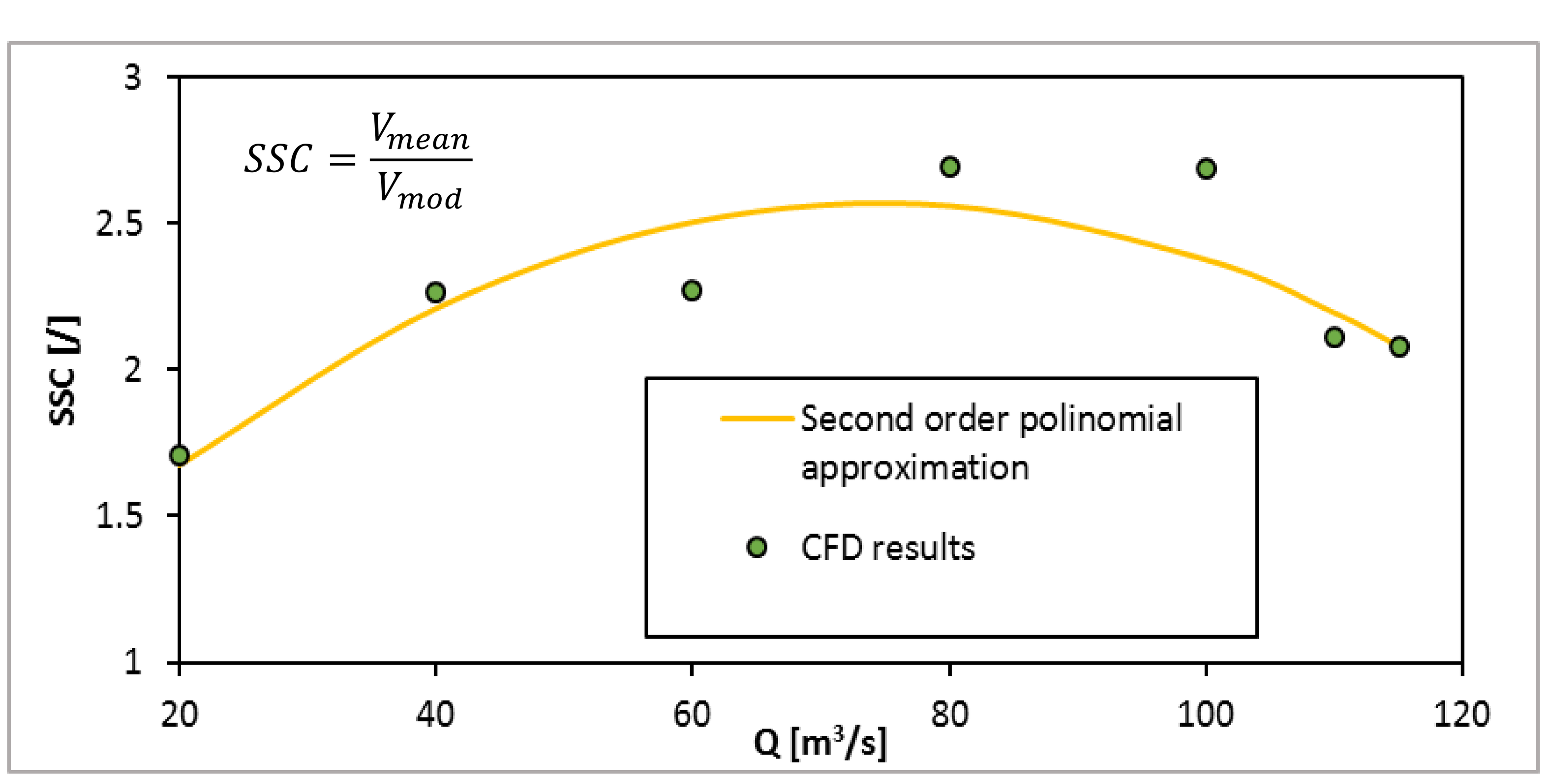


Figure 4. SSC curve for the flat EM3 probe in the FP-BA tunnel entrance building

Case study

The site-specific calibration procedure is being tested on the derivational tunnel within hydropower system (HPS) of Trebinje, where flow measurement system was installed (Fig 2). The tunnel length is 14 km and diameter is varying from 6.4 up to 7.5 m. **Flow rate changes** during the year from dry conditions (**0 m³/s**) up to **160 m³/s**, having both free surface and pressurized flow. In the measuring section, **4 flat EM probes** plus 2 special log-probes were installed (Figure 2, left). Site-specific calibration procedure for a single EM sensor is also being tested on the lab flume at a Faculty of Civil Engineering, University of Belgrade.

Results and Discussion

In the presented results, manufacturer's 1D weighting function was used and combined with velocity profiles sampled along perpendicular integration lines (Fig 2, right). An example SSC curve for the EM3 probe was computed (Fig 3). It can be seen that the **difference between the modelled and mean velocity is large** in case of the sensor EM3 (**SSC > 1.5**). It is assumed that both the limited integration zone and local geometry influenced the "mean" velocity measurements. Preliminary results show that the site-specific calibration procedure is justified and should be employed prior to the flat EM sensor usage. Further lab testing is planned in order to determine the achieved reduction in flow rate bias and systematic uncertainty as well as the potential drawbacks of the presented methodology.

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