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Flow measurements in non-standard conditions

Supported by

Prof. Dušan Prodanović, D.Sc

University of Belgrade, Faculty of Civil Engineering,
Chair of Hydraulic and Environmental Engineering

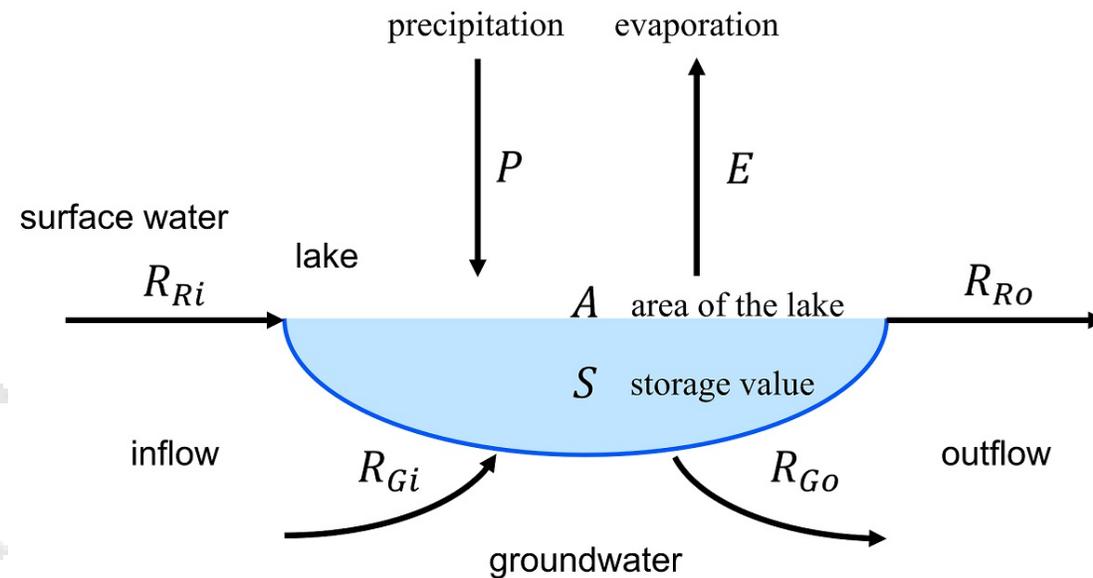celebrating 175th Anniversary of the Faculty of Civil Engineering, University of Belgrade

Conference title: **Achievements** and Visions

In: **Flow measurements in non-standard conditions**

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To monitor the (water) balance (money) (Covid-19) (...whatever)

precipitation   evaporation

P E

surface water

R_{Ri} lake

A area of the lake R_{Ro}

S storage value

inflow

R_{Gi} R_{Go} outflow

groundwater

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Conference title: **Achievements** and Visions

In: **Flow measurements in non-standard conditions**

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Real-life situations are mostly out-of-standards!
We need excellent scientific background to accomplish measurement task

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Conference title: Achievements and **Visions**

In: **Flow measurements in non-standard conditions**

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By: **support of old physicaly based EM method** bringing it to the next level (3+ D velocity meas.)

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Flow measurements in non-standard conditions

Few words about used method for flow measurement

- Different flow/velocity measurement methods exist

- Ultrasound popular – but measures velocity of particles

- Volumetric (PD) - accurate but not applicable for field work

- Coriolis – physically based, accurate, very expensive

- Electromagnetic (EM) method – physically based, can be tailored for different flow conditions, can measure velocity components, and we have domestic producer here in BGD
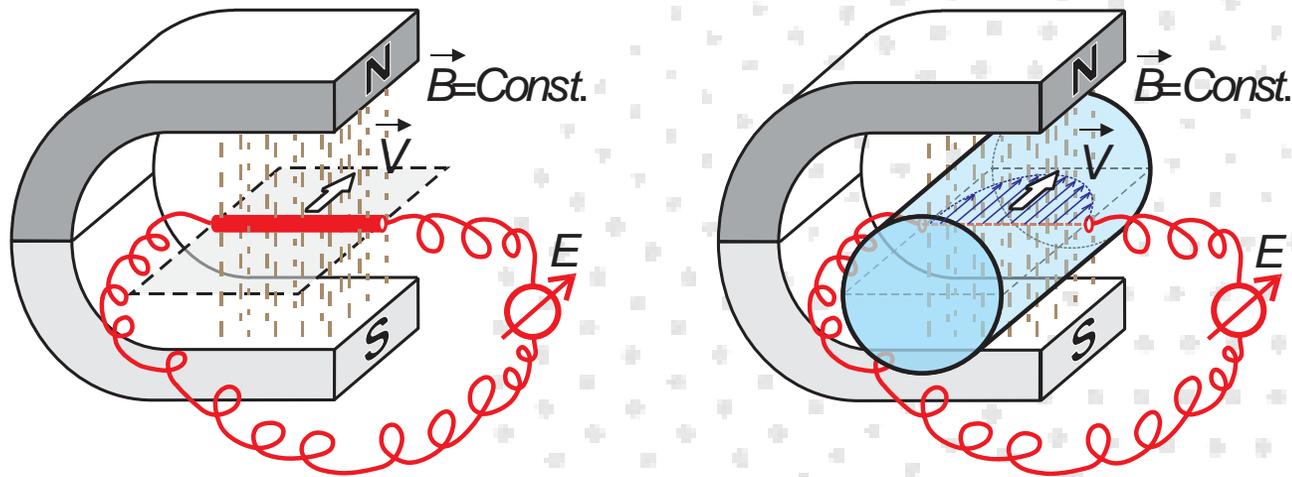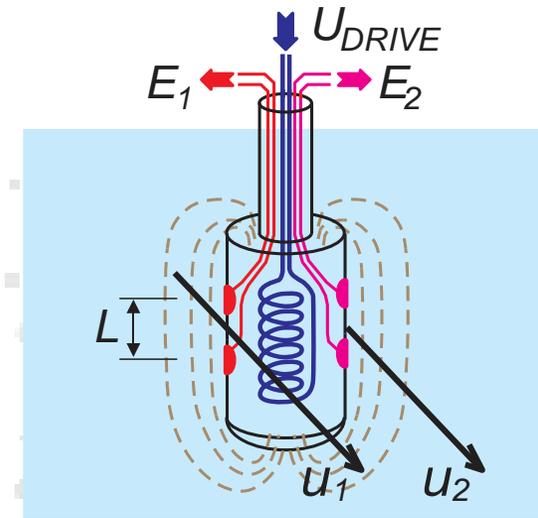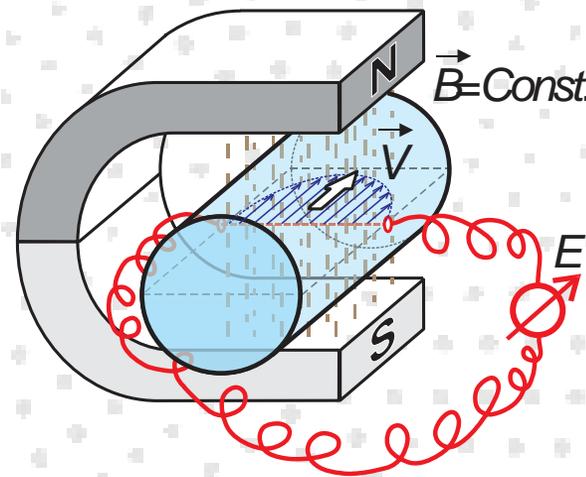
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Flow measurements in non-standard conditions

Few words about **used EM method** for flow measurement

- Method based on the Faraday's law of induction

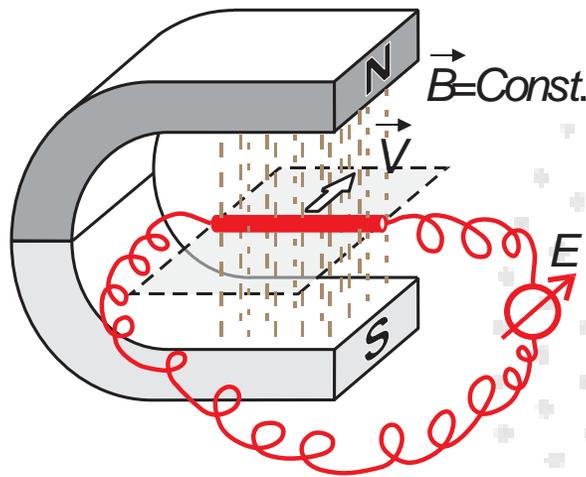$$E = - \int_{\tau} \left(\vec{V} \times \vec{B} \right) \cdot \vec{j} \, d\tau$$

Flow measurements in non-standard conditions

Few words about used EM method for flow measurement

- Method based on the Faraday's law of induction

- Mostly used for full pipe flow measurement

$$E = -\int_\tau \left(\vec{V} \times \vec{B} \right) \cdot \vec{j} \, d\tau$$

Flow measurements in non-standard conditions

Few words about used EM method for flow measurement

- Method based on the Faraday's law of induction

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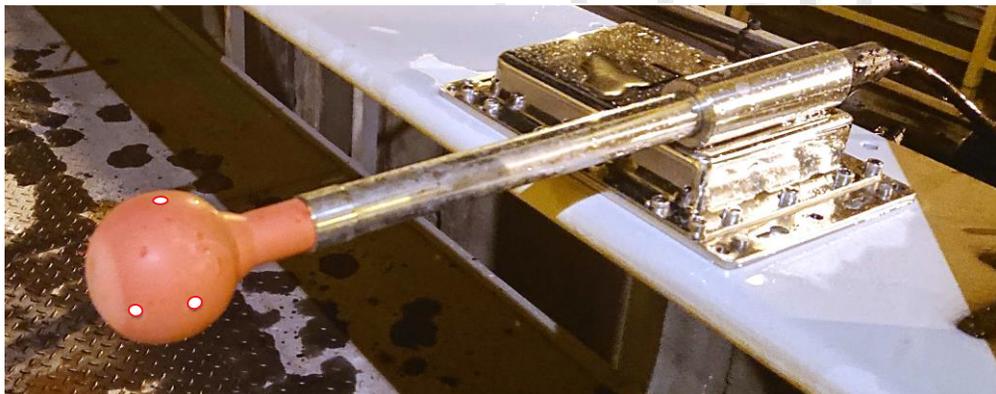- We use it for "point" (in small volume) velocity measurement

Flow measurements in non-standard conditions

Few words about used EM method for flow measurement

- Velocity probe can be shaped according to our needs

Flow dir.

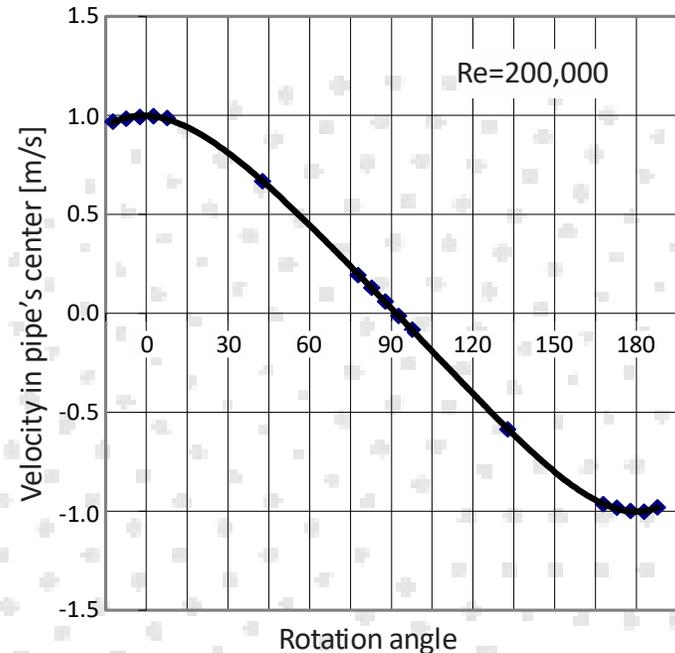celebrating 175th Anniversary of the Faculty of Civil Engineering, University of Belgrade
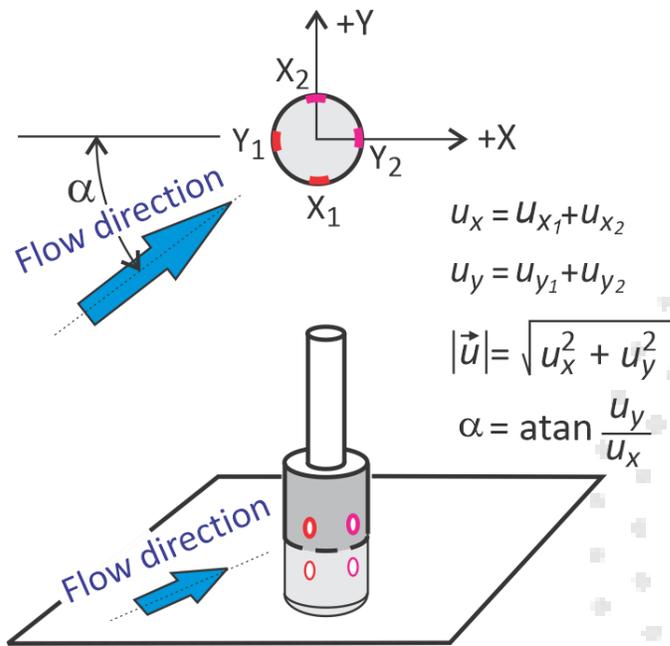
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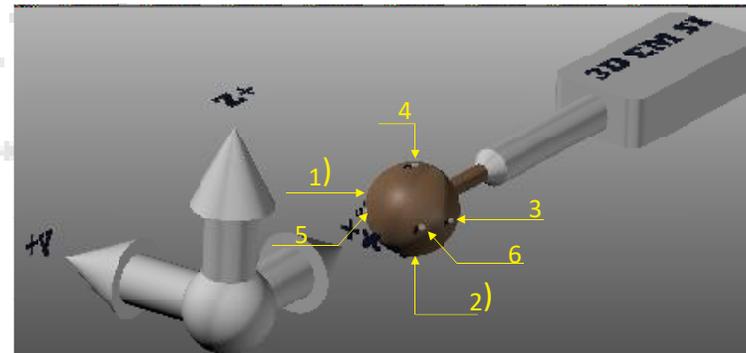# Flow measurements in non-standard conditions

Few words about used EM method for flow measurement

- Velocity probe can be shaped according to our needs

- It can measure velocity components, has cosine sensitivity

in 2D

$$u_x = u_{x_1} + u_{x_2}$$

$$u_y = u_{y_1} + u_{y_2}$$

$$|\vec{u}| = \sqrt{u_x^2 + u_y^2}$$

$$\alpha = \text{atan} \frac{u_y}{u_x}$$

Re=200,000

Velocity in pipe's center [m/s]

Rotation angle

in 3D or 3+ D

Flow measurements in non-standard conditions

What **non-standard conditions** are considered in the paper?

- Unsteady flow during the profiling
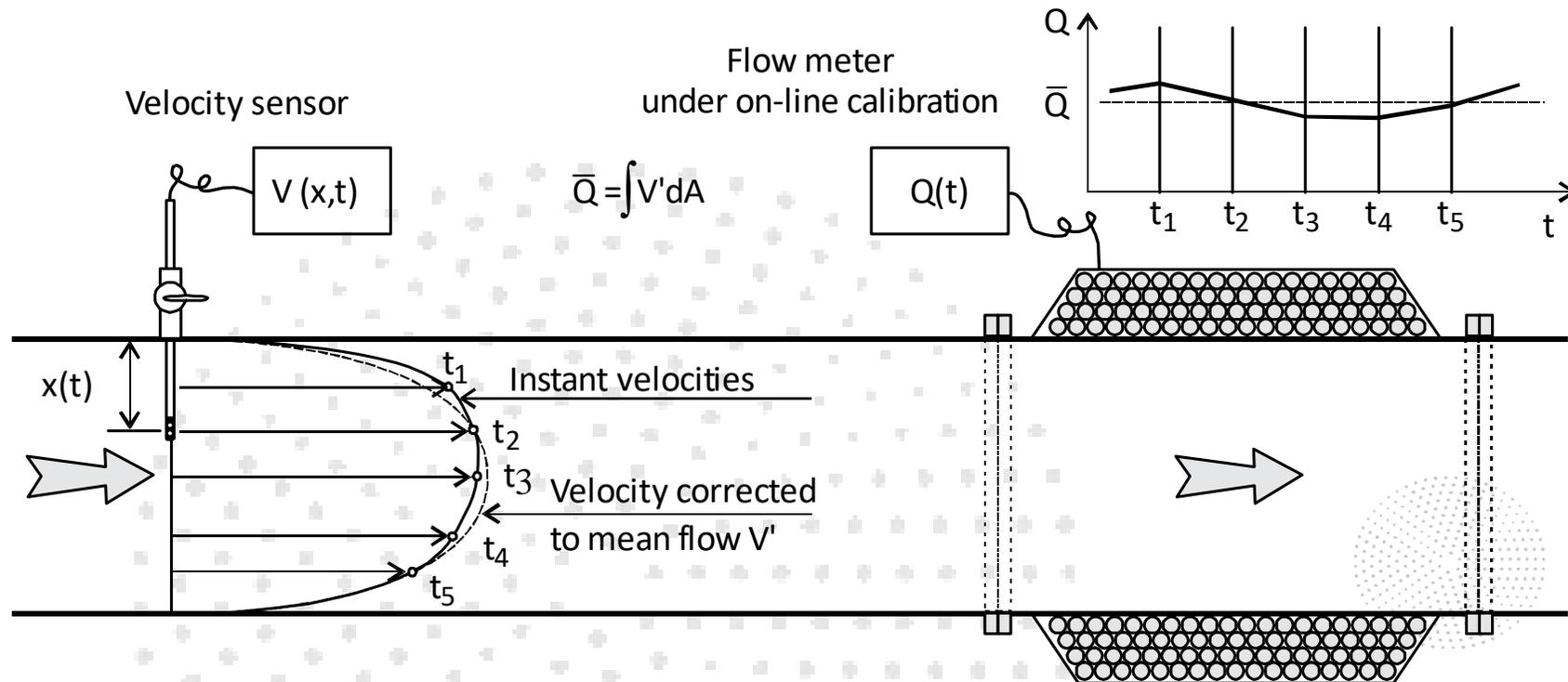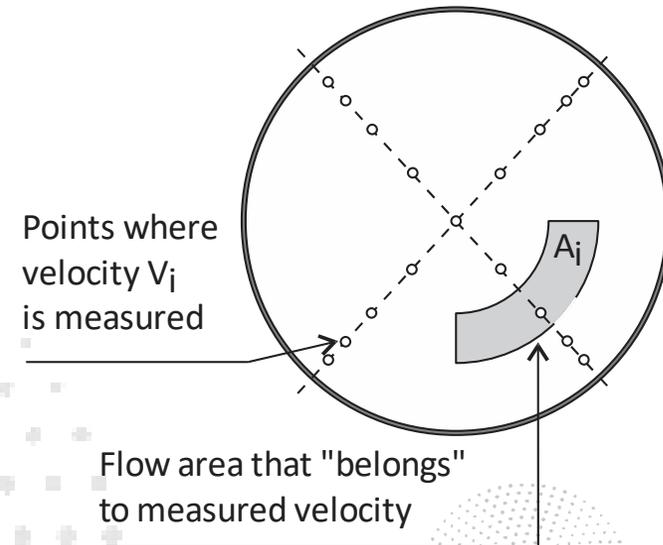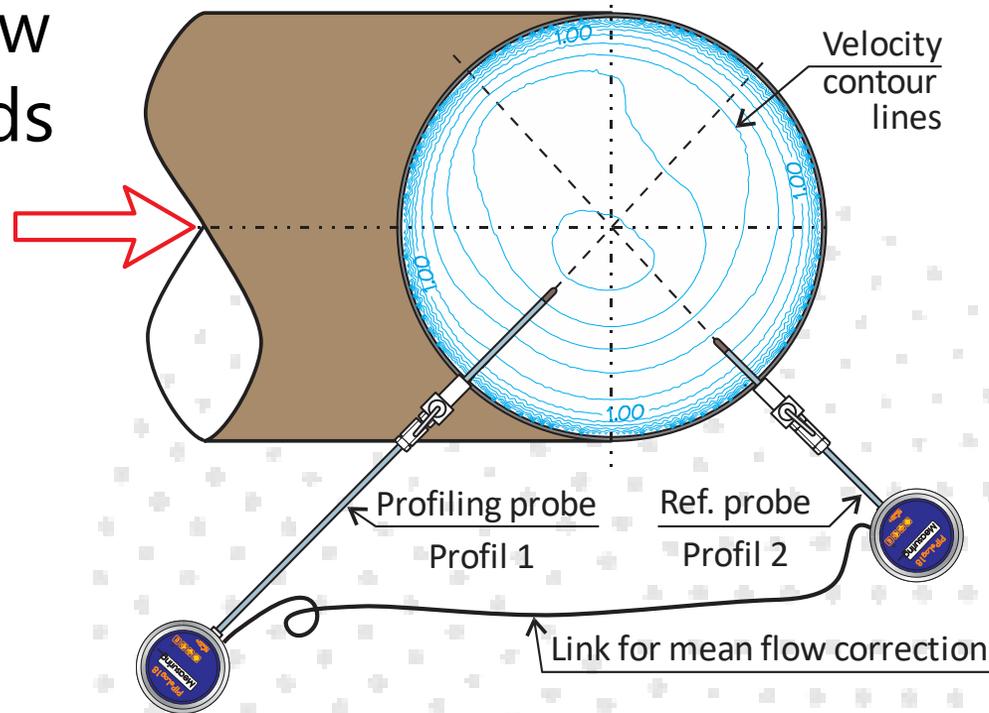
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Flow measurements in non-standard conditions

What non-standard conditions are considered in the paper?

- Unsteady flow during the profiling

- Irregular flow profile, needs more EM probes

Velocity contour lines

Profiling probe
Profil 1

Ref. probe
Profil 2

Link for mean flow correction

Points where velocity V_i is measured

A_i

Flow area that "belongs" to measured velocity

Calculated flow is: $Q = \Sigma V_i A_i$

where area is: $\Sigma A_i = \dfrac{D^2 \pi}{4}$

Case 1/4 – Water treat. plant Štrand, Novi Sad, 2000

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- Flow at old filter station with flow distribution to left and right filters

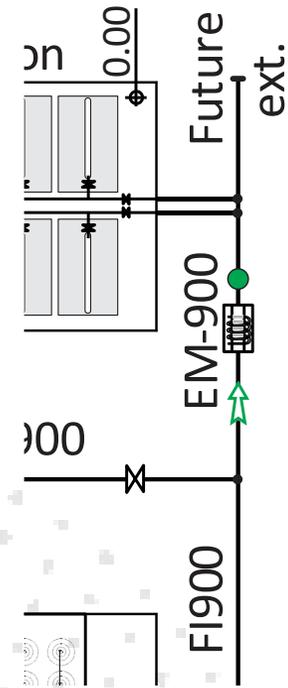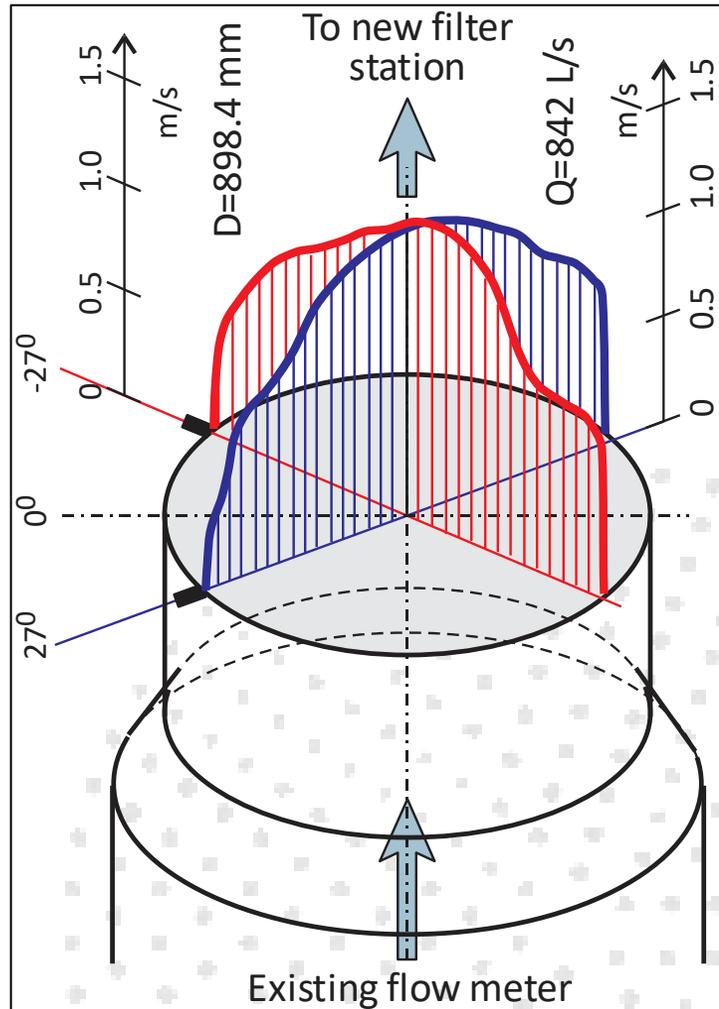- Recalibration of existing flow meter for new filter station, on-line

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Case 1/4 – Water treat. plant Štrand, Novi Sad, 2000

- Velocity profiled using two probes

- Unsteady flow corrected using existing flow meter

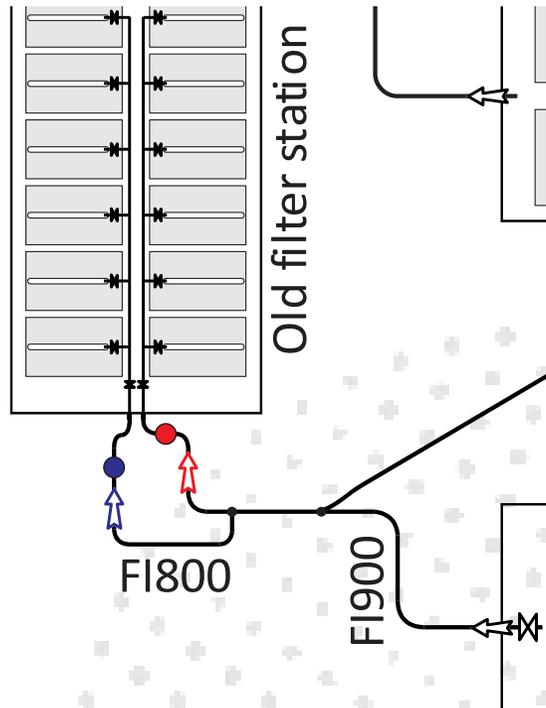- Recalibration of existing flow meter for new filter station, on-line
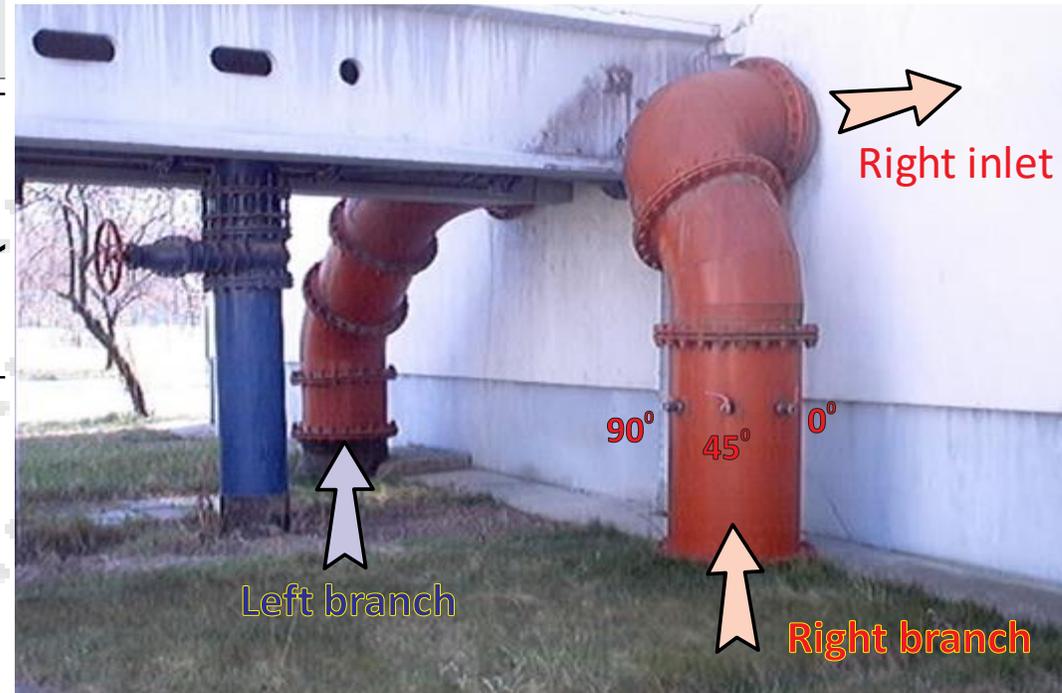
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Case 1/4 – Water treat. plant Štrand, Novi Sad, 2000

- Flow at old filter station with flow distribution to left and right filters

- Where to measure flow?

Old filter station

FI800

FI900

Right inlet

90° 45° 0°

Left branch

Right branch

Case 1/4 – Water treat. plant Štrand, Novi Sad, 2000

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- Profiling using two probes, one as a reference

- Streamwise velocity component shown

- Can we see the radial component?
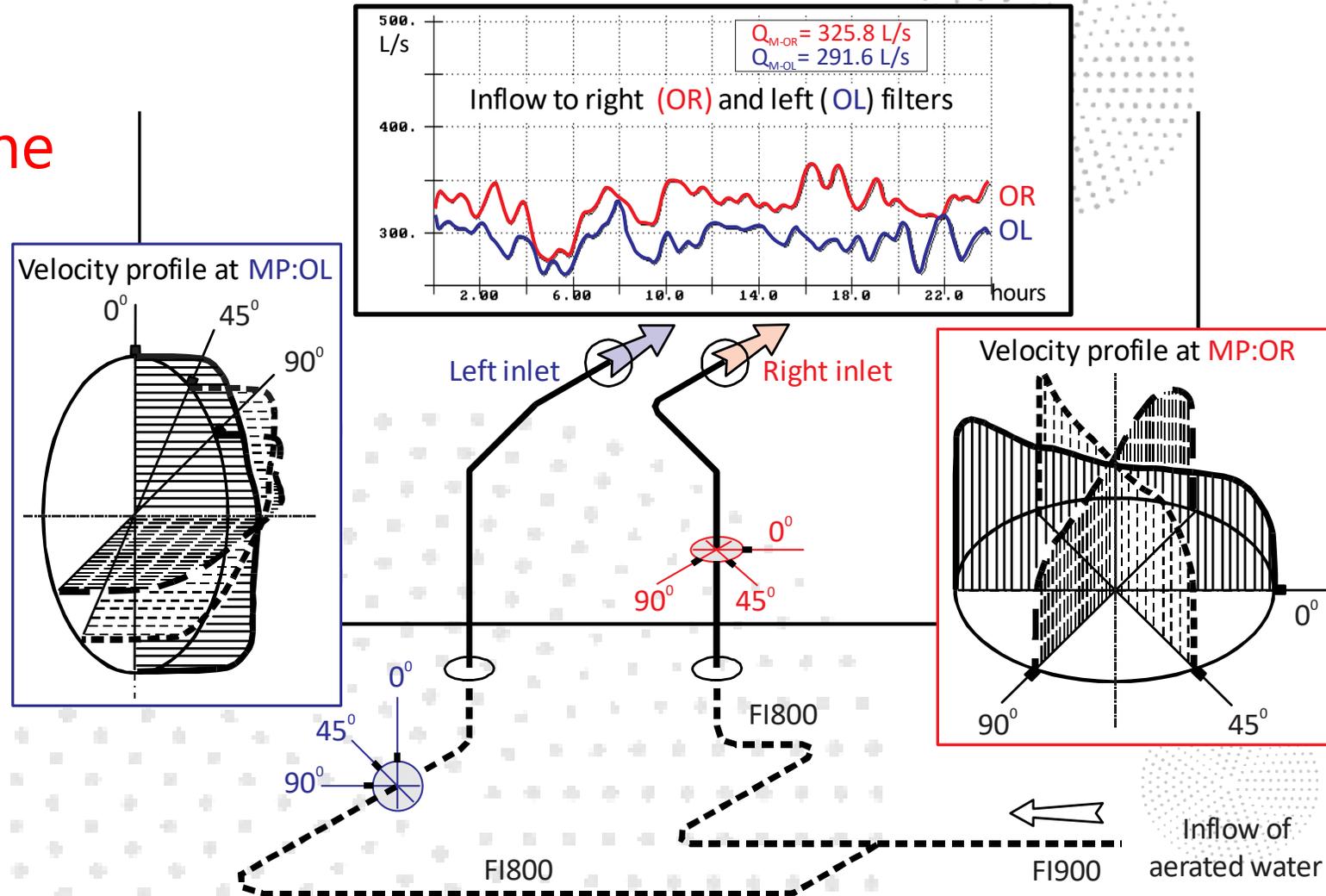
Velocity profile at MP:OL

0^0 45^0 90^0

$Q_{M\text{-}OR}$ = 325.8 L/s
$Q_{M\text{-}OL}$ = 291.6 L/s

Inflow to right (OR) and left (OL) filters

500. L/s
400.
300.

2.00 6.00 10.0 14.0 18.0 22.0 hours

OR
OL

Left inlet   Right inlet

0^0
90^0 45^0

FI800

0^0
45^0
90^0

Velocity profile at MP:OR
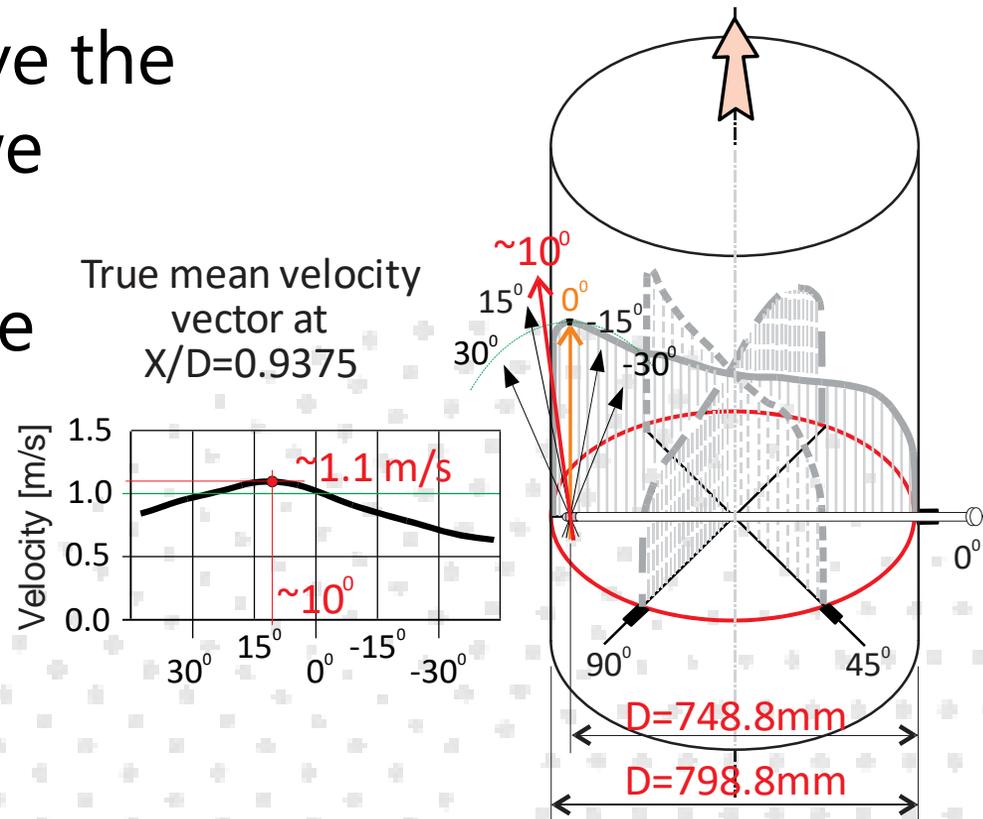
90^0 45^0 0^0

FI800

FI900

Inflow of aerated water

Case 1/4 – Water treat. plant Štrand, Novi Sad, 2000

The radial component

- We did not have the 2D probe, so we have to rotate 1D probe

True mean velocity vector at X/D=0.9375
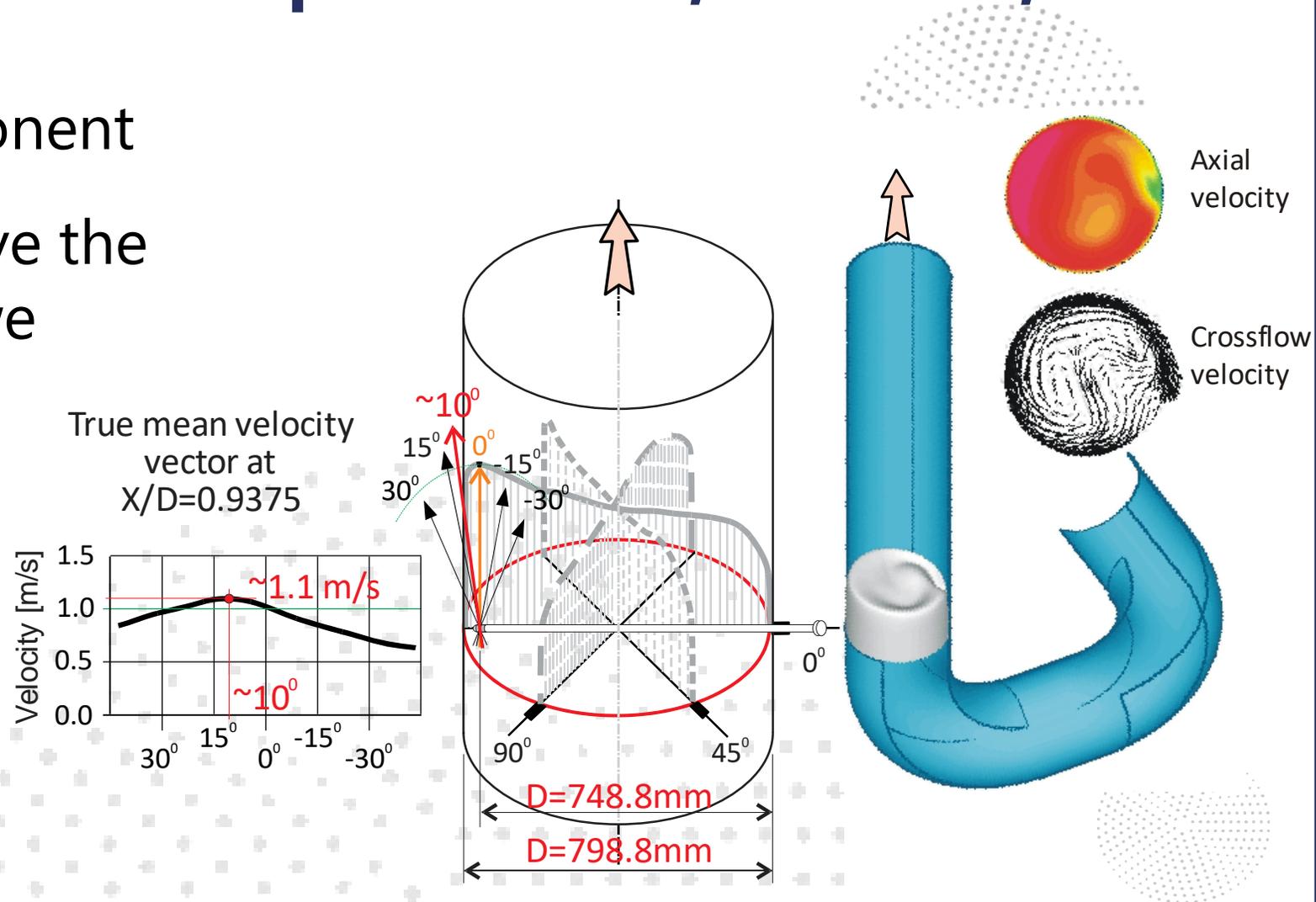
~1.1 m/s

D=748.8mm
D=798.8mm

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Case 1/4 – Water treat. plant Štrand, Novi Sad, 2000

The radial component

- We did not have the 2D probe, so we have to rotate it

- CFD results for similar flow conditions (Sontex, 2002)

True mean velocity vector at X/D=0.9375

~10⁰

~1.1 m/s

~10⁰

D=748.8mm
D=798.8mm

Axial velocity

Crossflow velocity

Case 2/4 – Topčider valley, Belgrade, 2004

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Verification of built-in flow meters on large pipes (FI 1500 mm)

- Installed at wrong position

- Have suspicious readings...

- although from respectable company
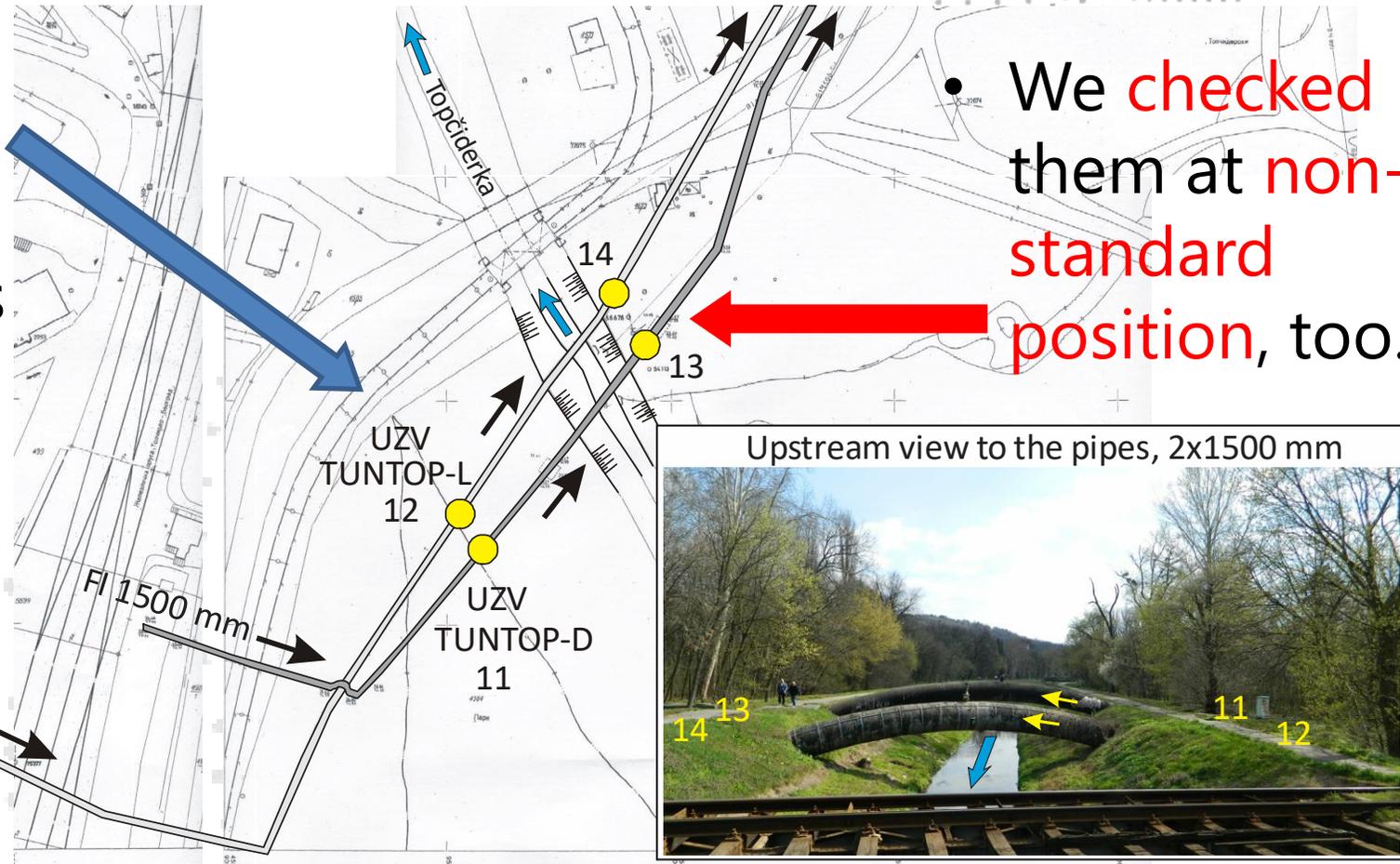
- We checked them at non-standard position, too.

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Upstream view to the pipes, 2x1500 mm

Case 2/4 – Topčider valley, Belgrade, 2004

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Verification of built-in flow meters on large pipes (FI 1500 mm)

- Verified using two types of profiling probes

- Velocity profile highly irregular

EM probe measurements

Spectrascan measurements

Interpolated

Extrapolated (3 variants)

Theorethical velocity for $Q_{UZV-11-REF} = 1.588$ m^3/s

Theorethical velocity for $Q_{UZV-12-REF} = 2.17$ m^3/s

$Q_{13} = 1.586 / 1.658 / 1.717$

Calculated flow for different extrapolations

$Q_{14} = 1.772 / 1.846 / 1.917$

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Case 2/4 – Topčider valley, Belgrade, 2004

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Verification of built-in flow meters on large pipes (FI 1500 mm)

- Verified using two types of profiling probes

- Velocity profile highly irregular

- Third checked using CFD
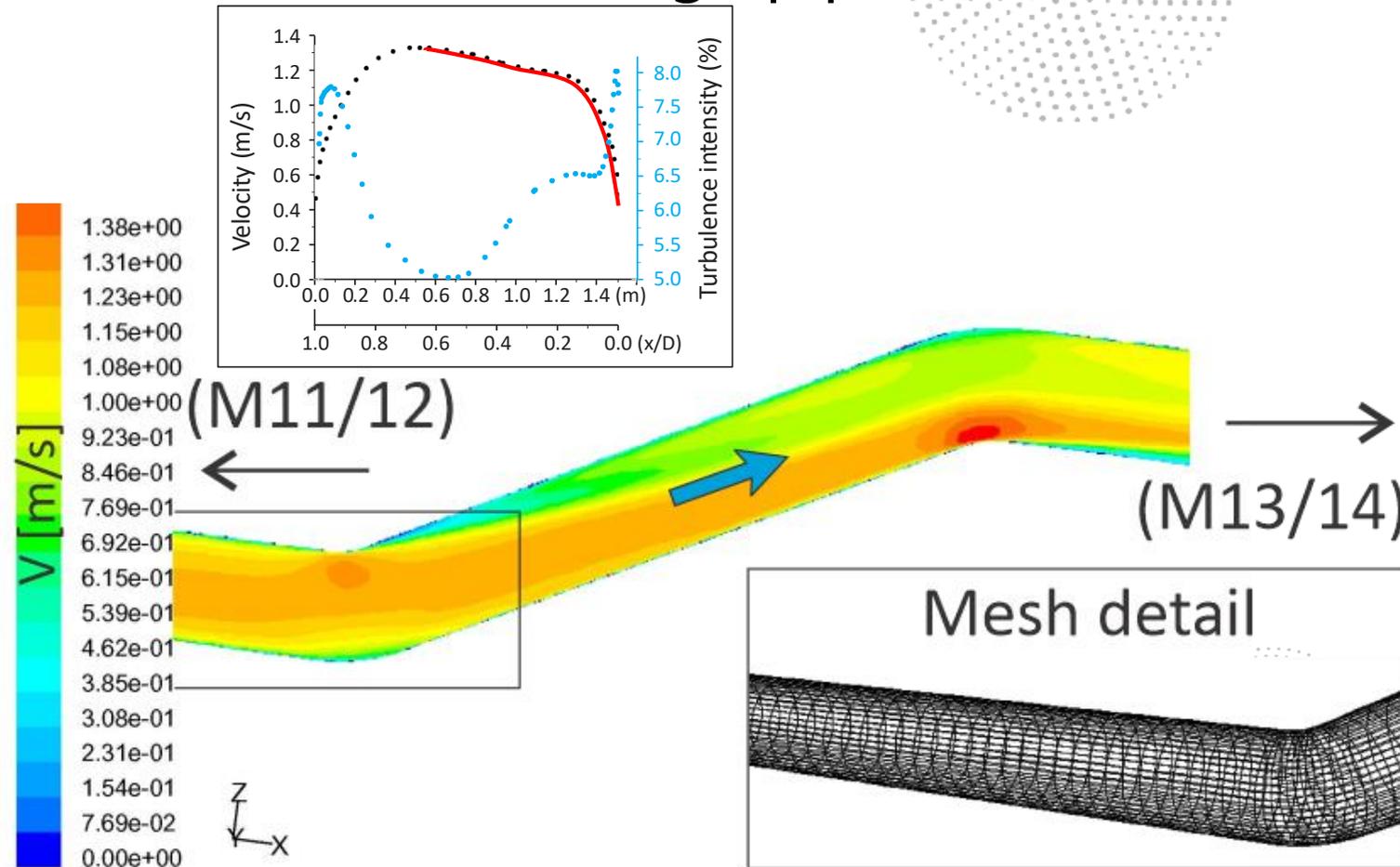
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Case 3/4 – Large tunnel, Trebišnjica system, 2016-2017

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Large diameter tunnels

- Three profiles

- Dabarsko-Fatničko polje D=5m, bidirectional flow

- Fatničko polje-Bilećko jez. D=6,5 and 5,4 m big difference in inflow and outflow due to exfiltration/infiltration

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Case 3/4 – Large tunnel, Trebišnjica system, 2016-2017

Large diameter tunnels: Dabarsko-Fatničko polje, D=5m
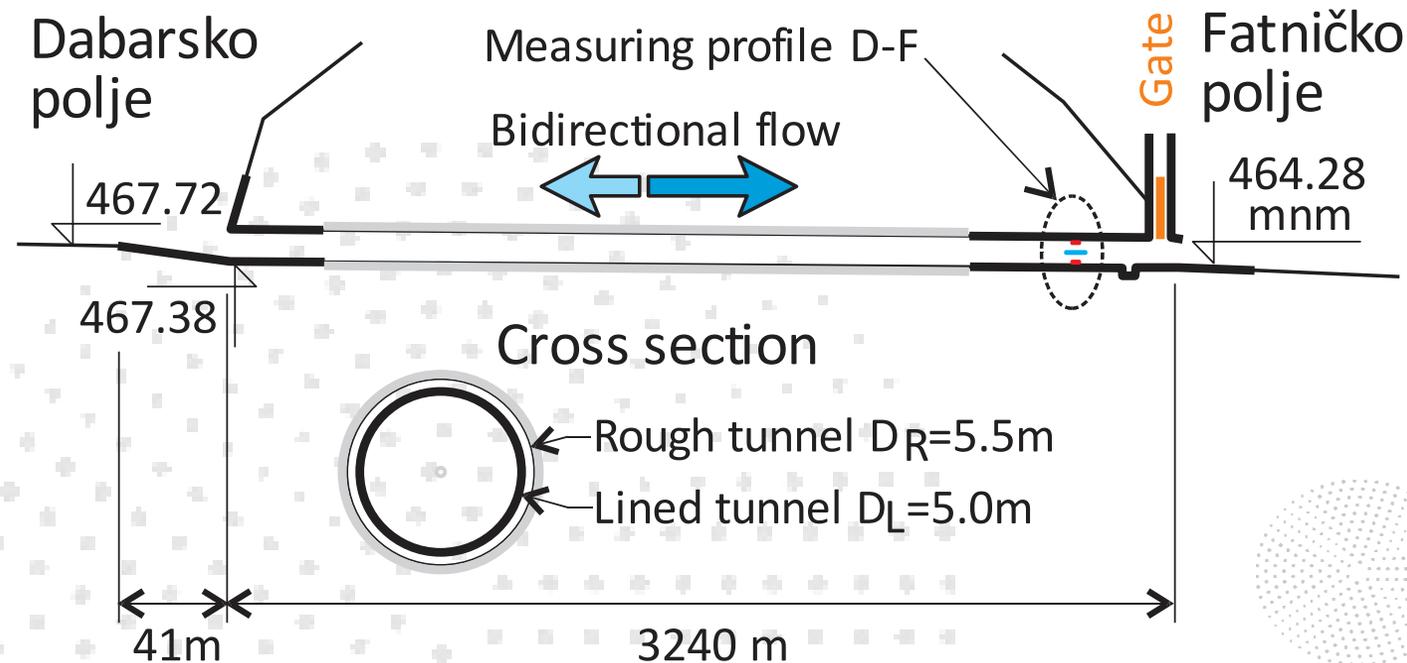
- Bidirectional flow

Dabarsko polje

Measuring profile D-F

Gate

Fatničko polje

Bidirectional flow

467.72

464.28 mnm

467.38

Cross section
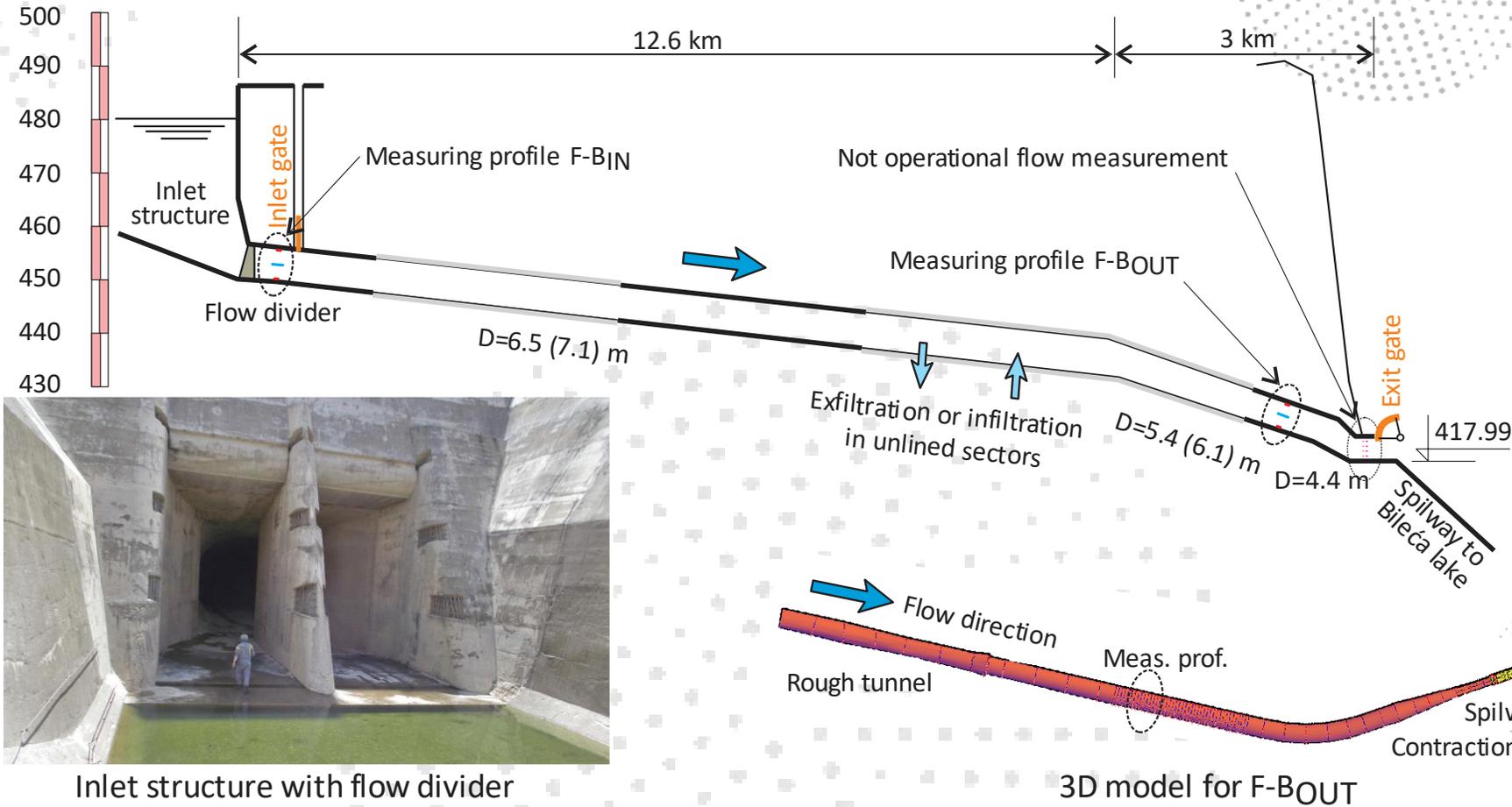
Rough tunnel D_R=5.5m

Lined tunnel D_L=5.0m

41m

3240 m

Case 3/4 – Large tunnel, Trebišnjica system, 2016-2017

Large diameter tunnels: Fatničko polje-Bileća lake 6,5 m & 5,4 m

Inlet structure with flow divider

3D model for F-B$_{OUT}$

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Case 3/4 – Large tunnel, Trebišnjica system, 2016-2017
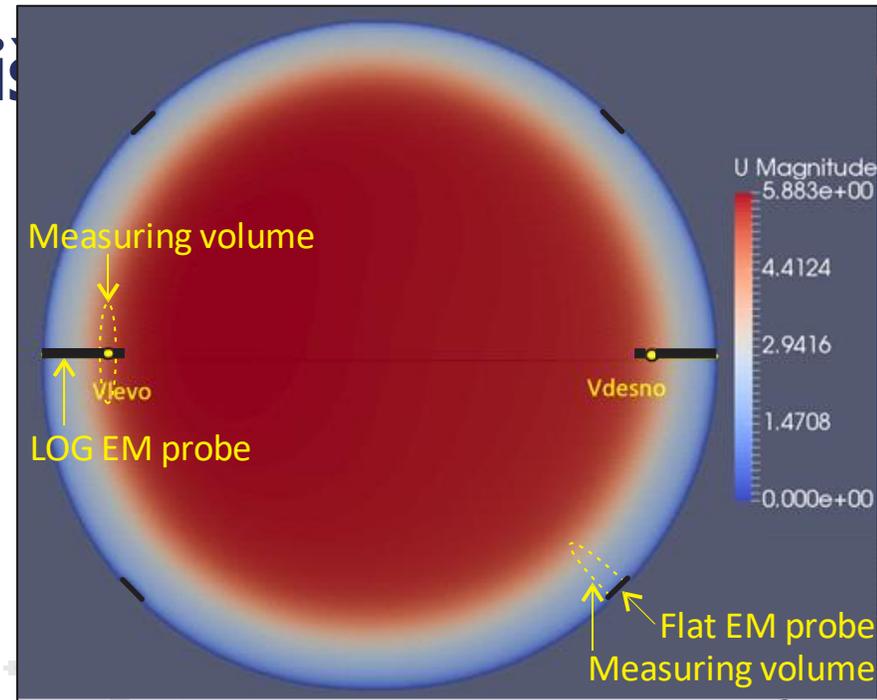
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Large diameter tunnels: solution

- Use 4 large flat probes, permanent instalation

- and 2 control, for one season

4x Flat EM probes

700 mm

2x Log EM probes

370 mm

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Before instalation of Em's

and during instalation

D-F tunnel

464.490 mnm

0.93

4.916 m

0.72 m

4.965 m
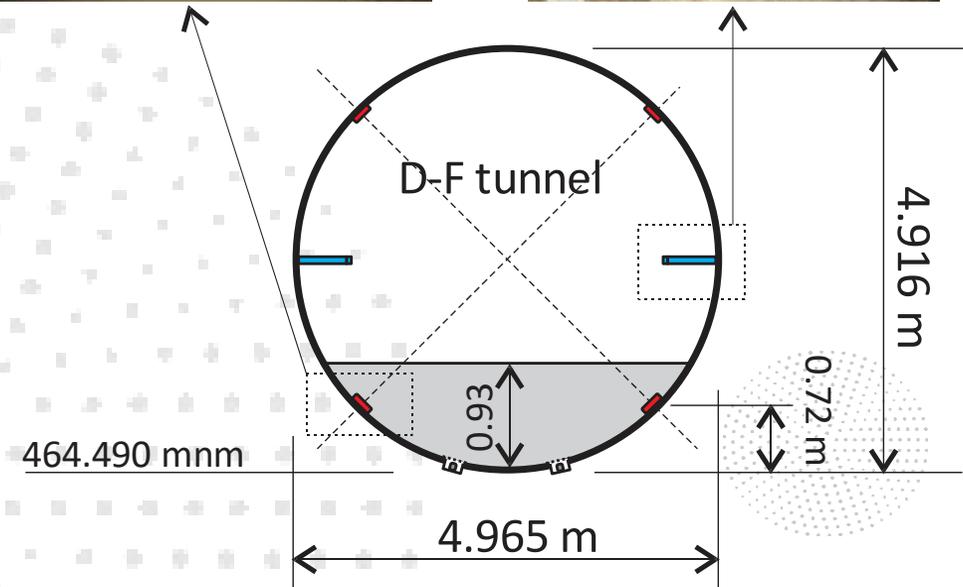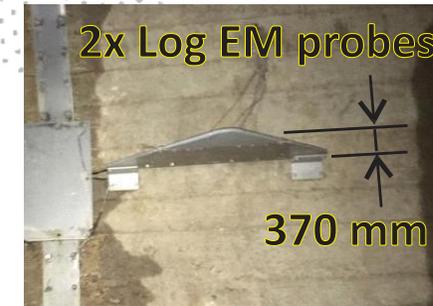
Case 3/4 – Large tunnel, Trebi... 17

Large diameter tunnels: solution

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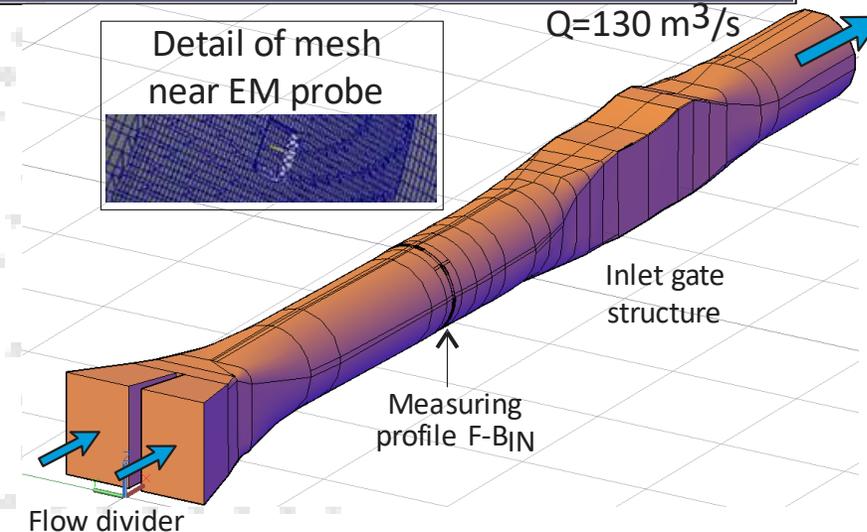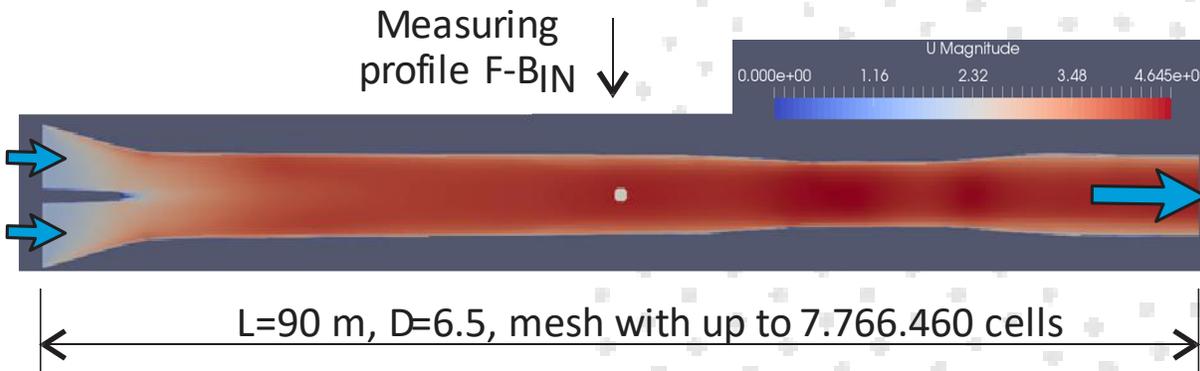- and 2 control, for one season

- Predict profile using CFD

Measuring volume
Vlevo — Vdesno
LOG EM probe
Flat EM probe
Measuring volume
U Magnitude
5.883e+00
4.4124
2.9416
1.4708
0.000e+00

Q=130 m^3/s

Detail of mesh near EM probe

Inlet gate structure

Measuring profile F-B$_{IN}$

Flow divider

Measuring profile F-B$_{IN}$

U Magnitude
0.000e+00   1.16   2.32   3.48   4.645e+00

L=90 m, D=6.5, mesh with up to 7.766.460 cells

Case 4/4 – Intake structure to HE Đerdap 2, 2020

Flow measurement of tube turbines with irregular inflow condit.

- Flow measured with WK method

- During exploitation problem confirmed
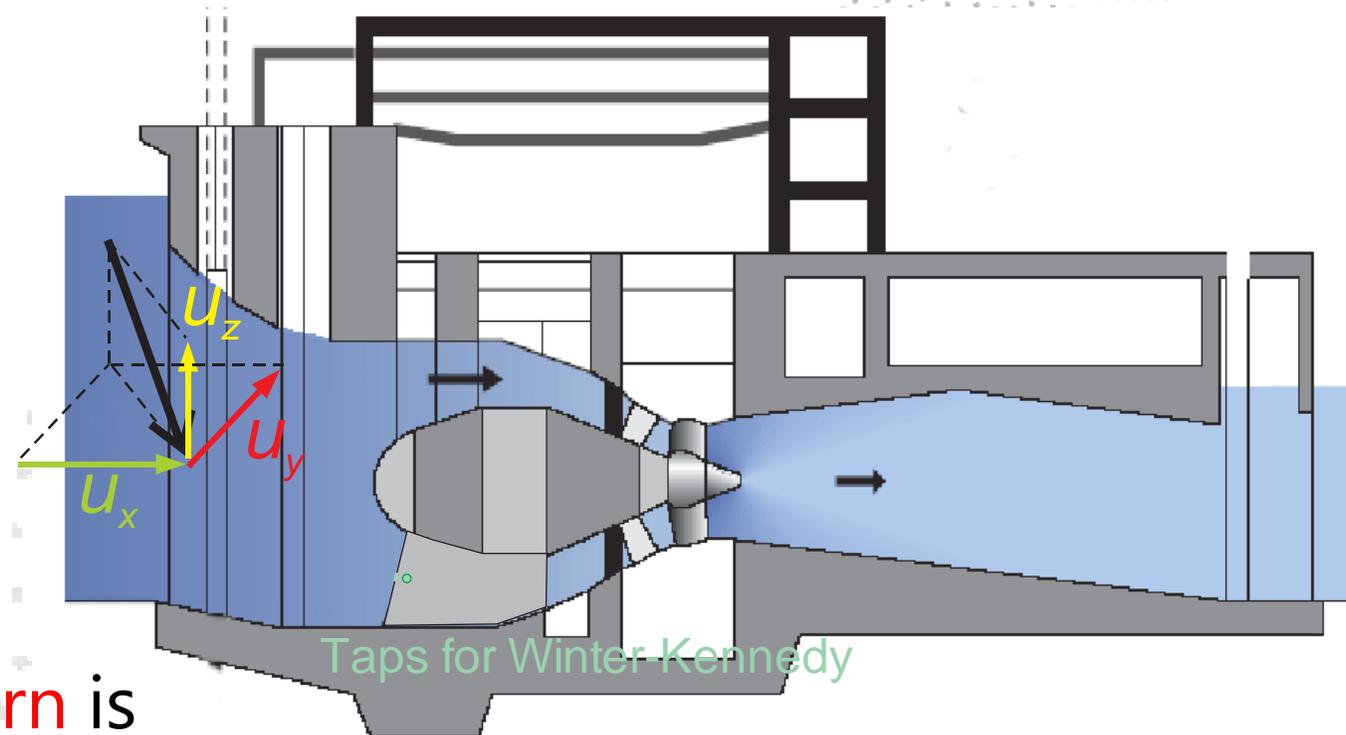

Romanian turbines
Serbian turbines
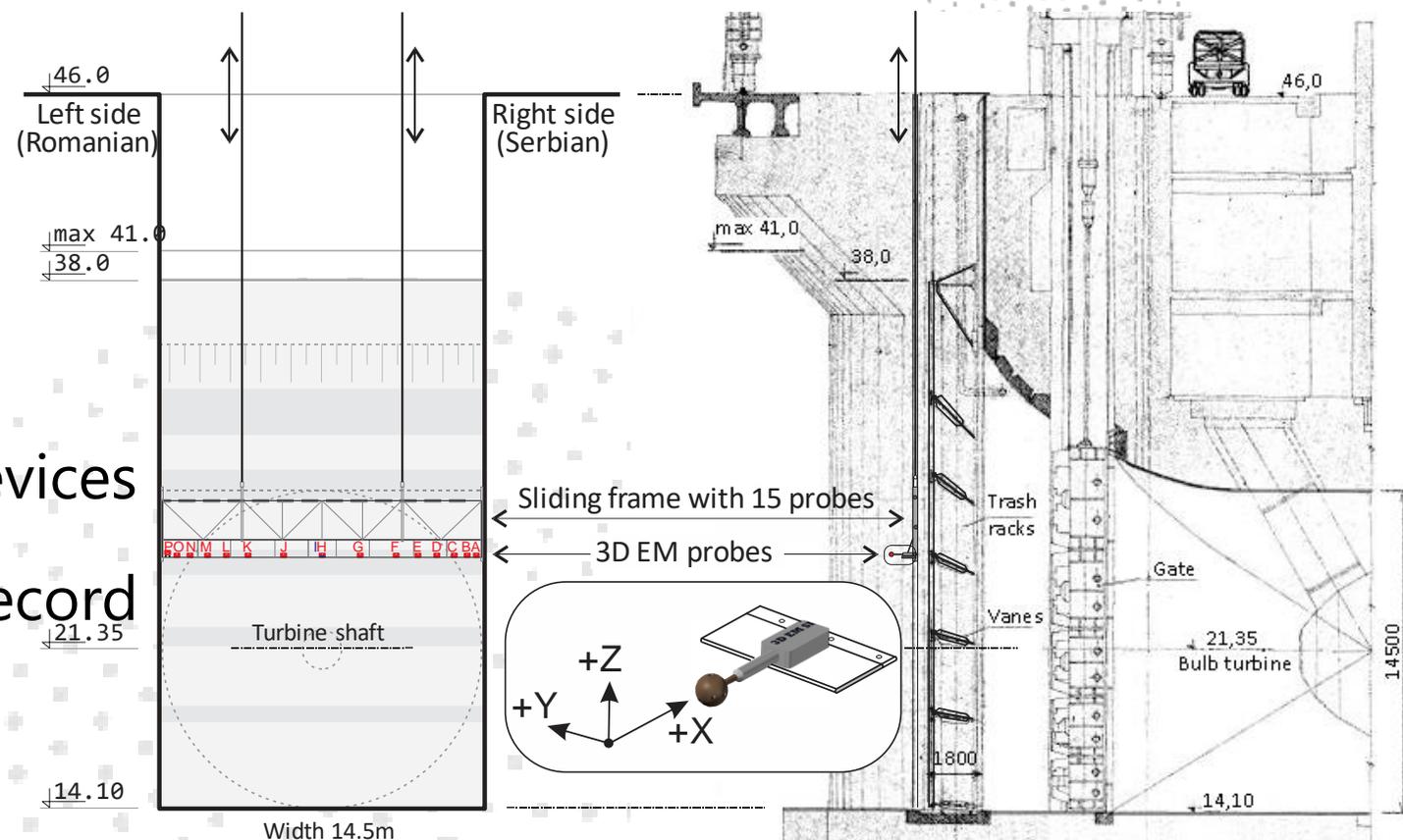
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Case 4/4 – Intake structure to HE Đerdap 2, 2020

Flow measurement of tube turbines with irregular inflow condit.

- Flow measured with WK method

- During exploitation problem confirmed

- because inflow pattern is not the same as on model

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Taps for Winter-Kennedy

Case 4/4 – Intake structure to HE Đerdap 2, 2020

Flow measurement of tube turbines with irregular inflow condit.

- No standards

- Used approach:
  - Use one row of current meters
  - Use 3D capable devices
  - Move frame and record the velocity profile
  - Calculate the flow

Case 4/4 – Intake structure to HE Đerdap 2, 2020

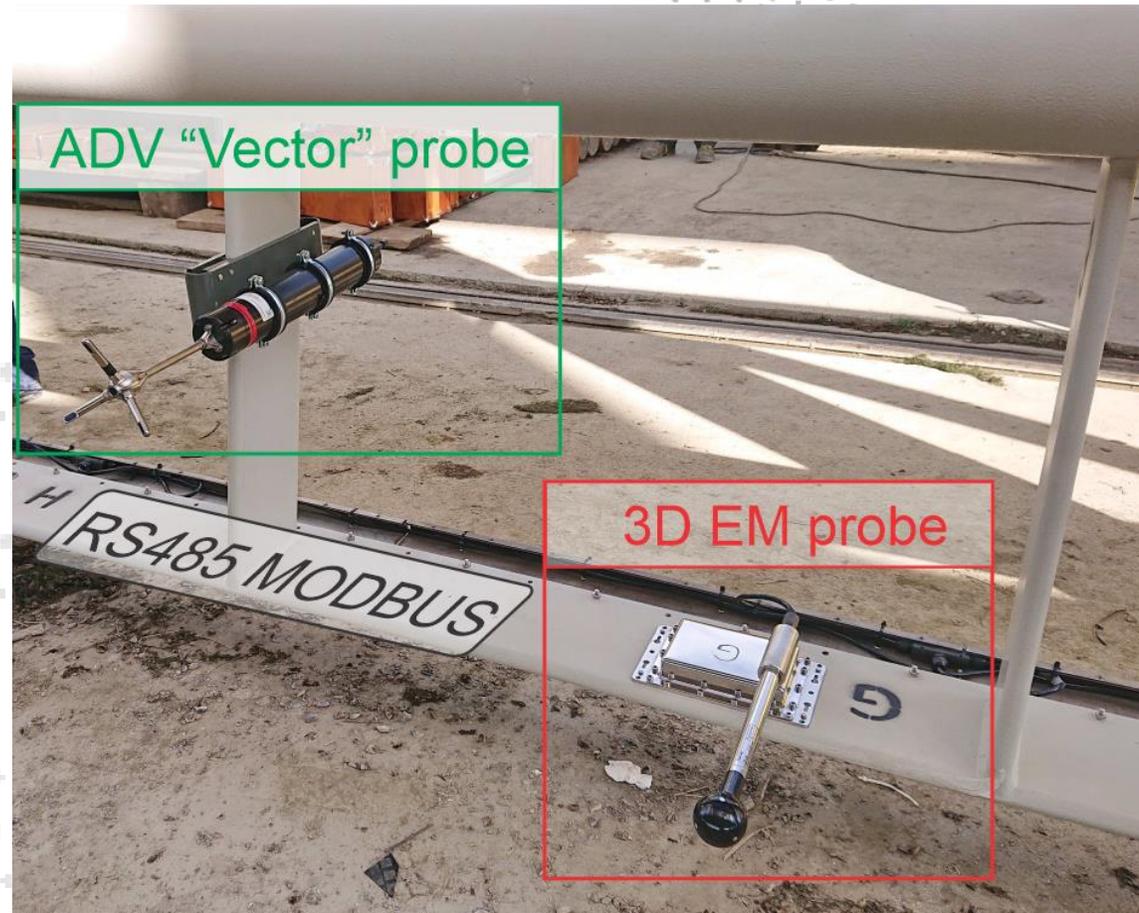Flow measurement of tube turbines with irregular inflow condit.

- Still frame 14,5 m long

Case 4/4 – Intake structure to HE Đerdap 2, 2020

Flow measurement of tube turbines with irregular inflow condit.

- Still frame 14,5 m long

- 15 EM 3+ D probes

- 2 ADV 3D probes

- Internal RS485 network

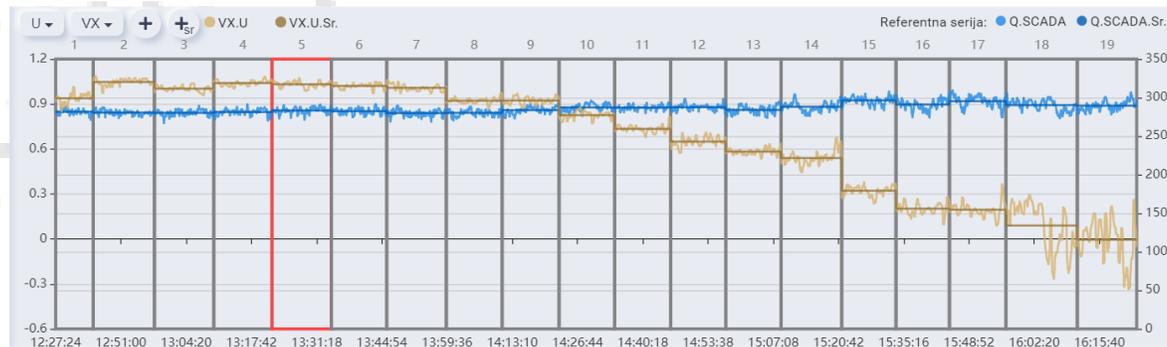celebrating 175th Anniversary of the Faculty of Civil Engineering, University of Belgrade

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Flow measurement of tube turbines with irregular inflow condit.

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- 2 position encoders, and

- 2 level pressure sensors

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Flow measurement of tube turbines with irregular inflow condit.

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- 2 position encoders, and

- 2 level pressure sensors

- plus SCADA turbine's data for turbine's unsteady flow

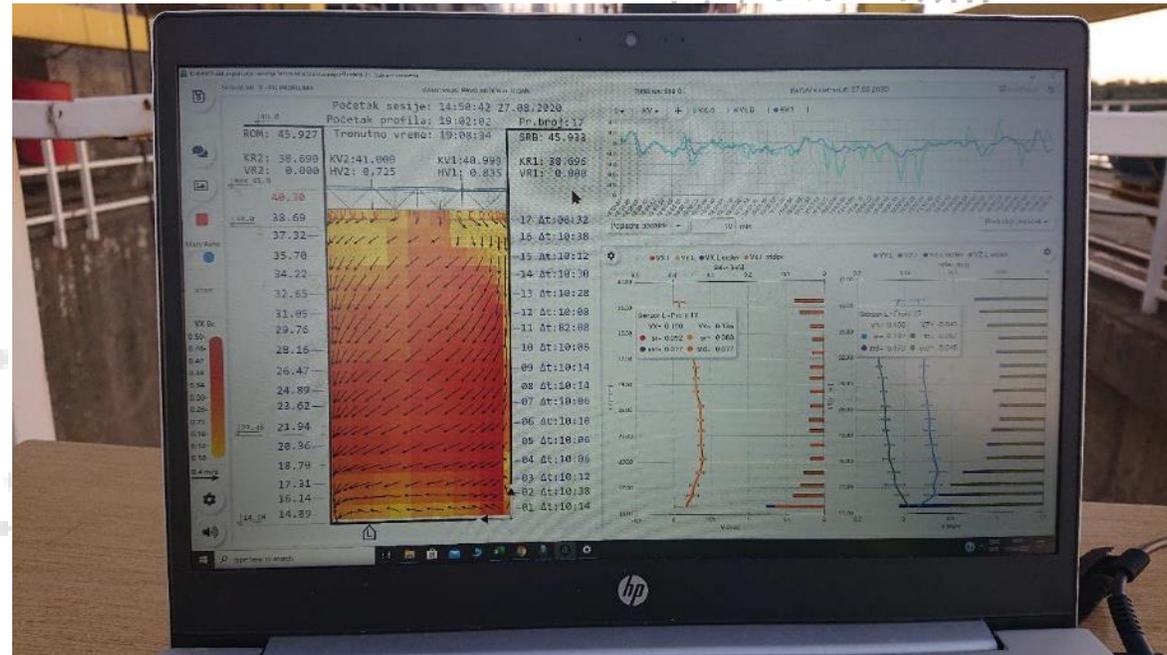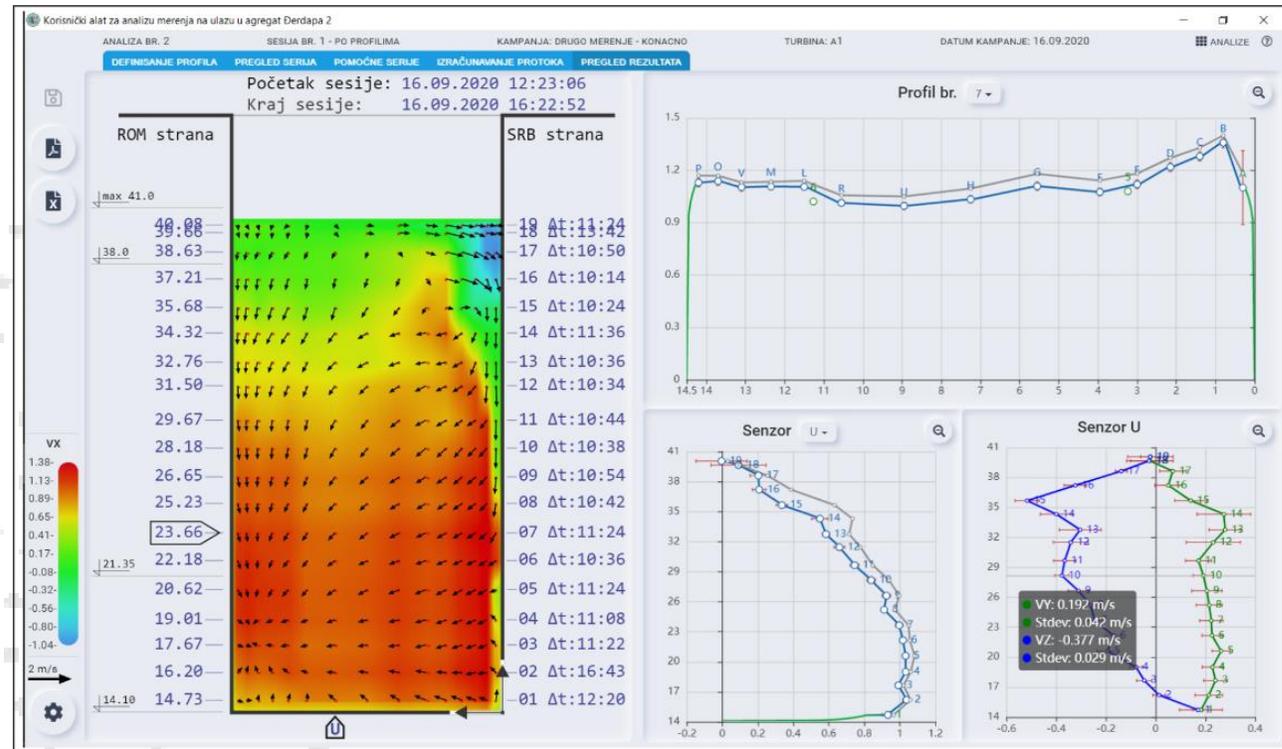celebrating 175th Anniversary of the Faculty of Civil Engineering, University of Belgrade
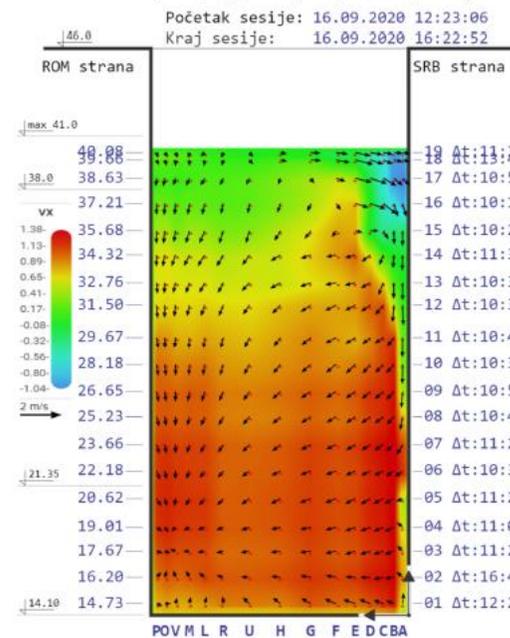
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Case 4/4 – Intake structure to HE Đerdap 2, 2020

Flow measurement of tube turbines with irregular inflow condit.

- Data acquisition software

Case 4/4 – Intake structure to HE Đerdap 2, 2020

Flow measurement of tube turbines with irregular inflow condit.

- Data acquisition software

- Data analysis software with SCADA and ADV integration

Case 4/4 – Intake structure

Flow measurement of tube turbine

- Data acquisition software

- Data analysis software with SCADA and ADV integration

- ...to final report:
  - Flow rate with uncertainty
  - Velocity distribution

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Записник са снимања поља брзина и обрачуна протока на турбини ХЕ Ђердап 2

Flow measurements in non-standard conditions

Conclusions

- No commercial devices for non-standard measurements.

- We have to combine different techniques,

- backuped by knowledge and equipment,

- and added uncertainty analysis,

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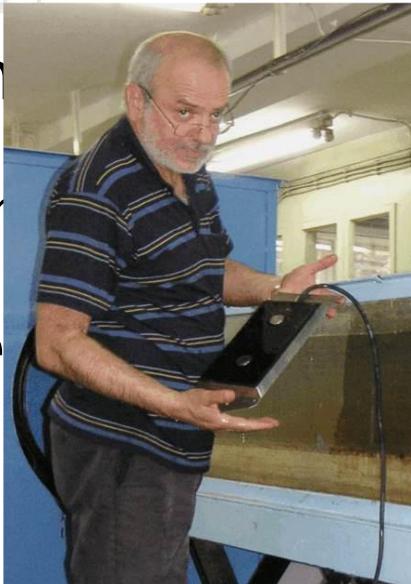Faculty of Civil
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Flow measurements in non-standard conditi

Conclusion

measure measurem

e o es

dge and equipment,

- and added uncertainty analysis, and…

- with a help of skillfull colleagues: prof. dr Čedo Maksimović, Mile Cvitkovac (Svet Instrumenata), doc. dr Dragutin Pavlović, doc. dr Damjan Ivetić, Predrag Vojt (IJČ), craftsmen and modelers Branko Hrkić and Ivor Koković ☺

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