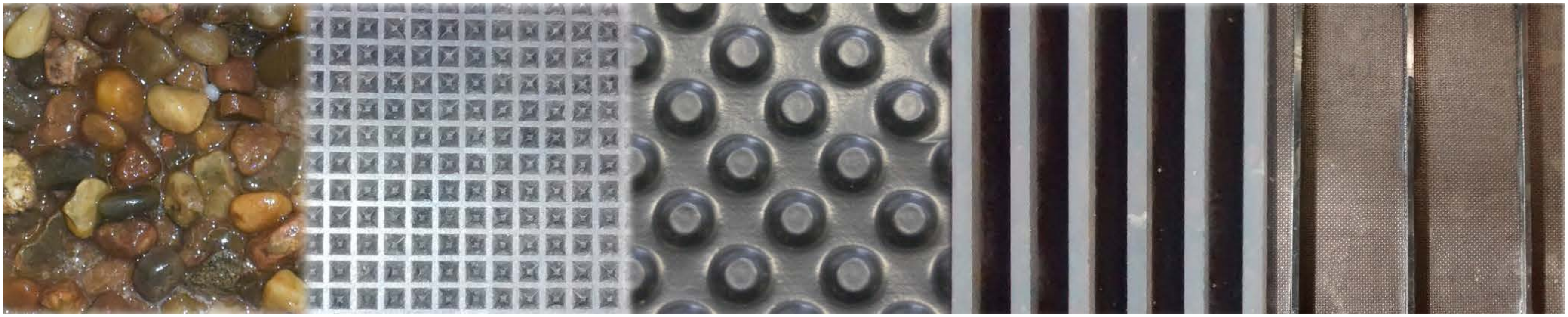
Experimental investigation of hydraulically different surface roughnesses



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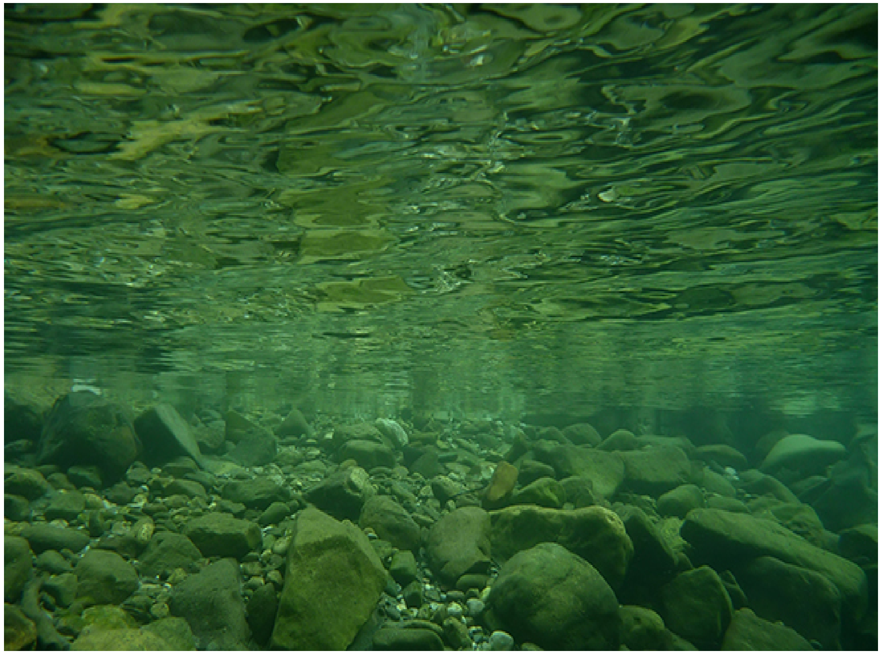
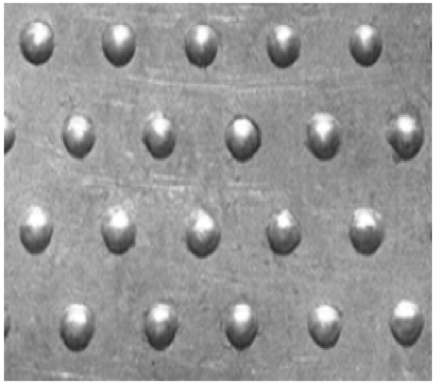
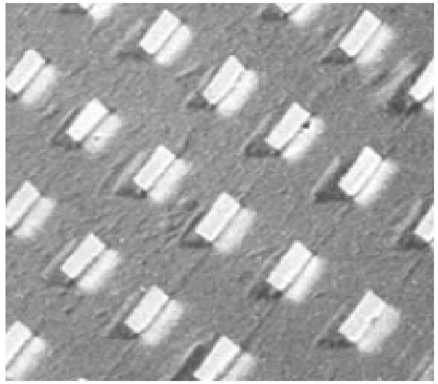
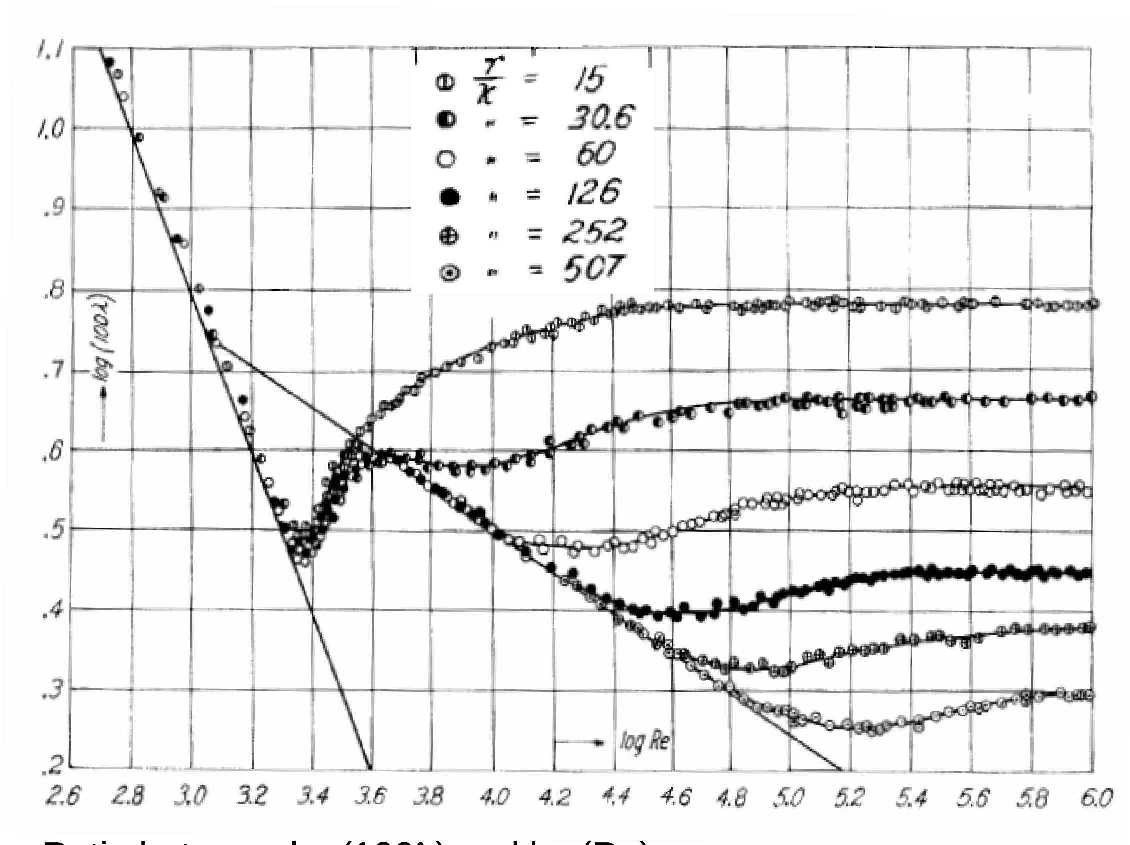
Introduction – Modelling of surface roughnesses



Theoretical background

Study of laws of flow in rough pipes (Nikuradse,1933)



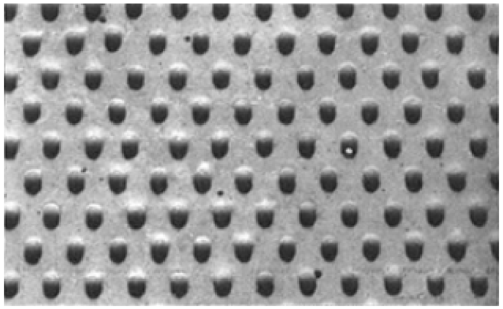
Ratio between log(100λ) and log(Re)

Systematic experiments at different *r/k.*

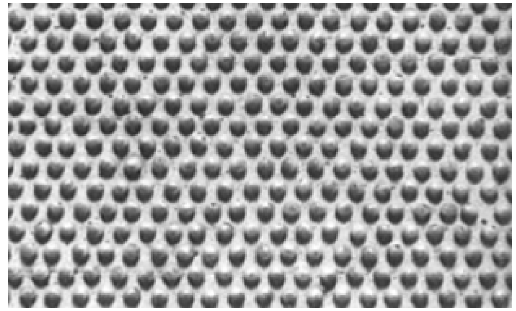
r = Radius of the pipe
k = Roughness height
λ = Resistance factor
Re = Reynolds number

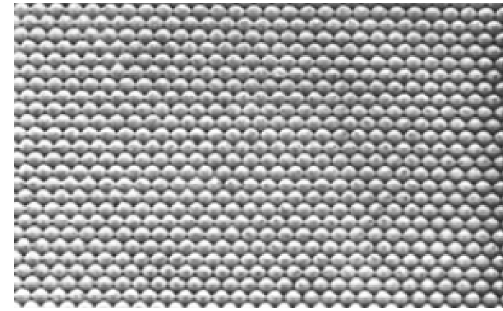
Theoretical background

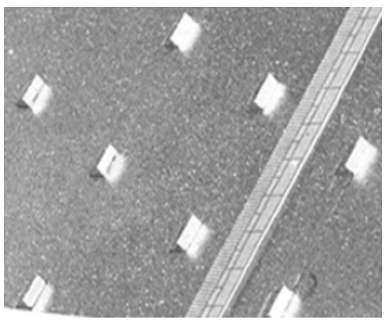
Experiments with different surface roughnesses (Schlichting, 1936)



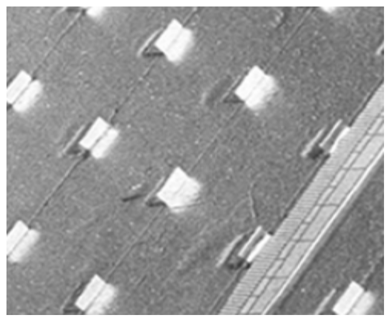
Spheres, k = 0.41 cm

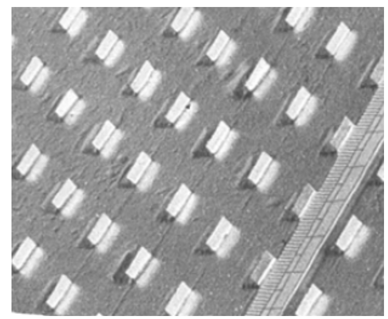


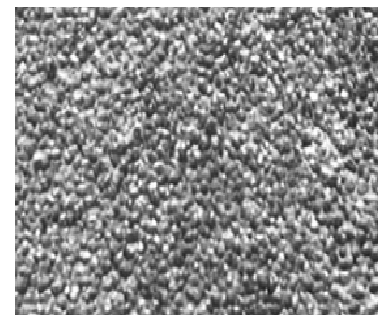




Angles, k = 0.30 cm







Hamburg sand,
k = 0.135 cm

- Maximum resistance at the intermediate density;
- Lower resistance for regular roughness elements than for irregular sand.

Theoretical background

Morris (1955)

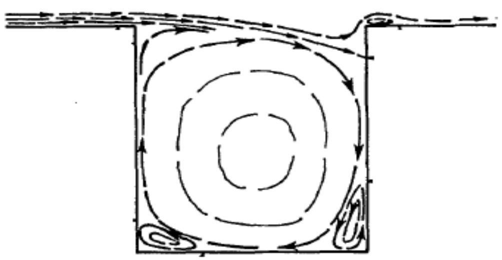
Quasi smooth (dense elements)

Wake interference (intermediate condition)

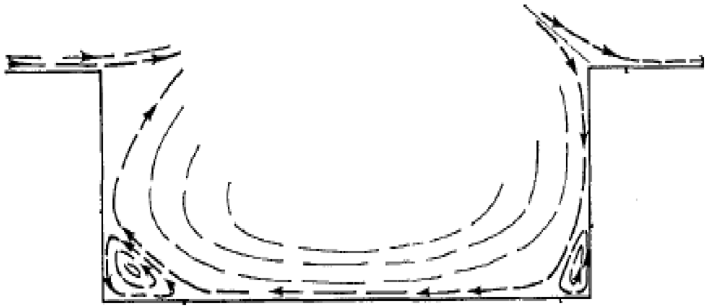
Isolated obstacles (wide spacing)

Perry et al. (1969)

- *d*-type: Flow field turbulence determined by the water depth.
- *k*-type: Roughness proportional to the height of the elements.



d-type



k-type

Theoretical background

Double averaged Navier-Stokes equations

$$\rho g S_b + \frac{1}{\phi}\frac{\partial \phi \tau}{\partial z} - f_p - f_\nu = 0$$ (Nikora et al. 2007a)

$$\tau = \rho\left[-\left\langle\overline{u'w'}\right\rangle - \left\langle\tilde{u}\tilde{w}\right\rangle + \frac{\nu}{\phi}\frac{d\phi\left\langle\overline{u}\right\rangle}{dz}\right]$$

ρ = Fluid density

g = Gravity acceleration

S_b = Bed slope

ϕ = Roughness geometry function

τ = Total fluid stress

z = Vertical coordinate

f_p = Form drag

f_ν = Viscous drag

ν = Kinematic viscosity

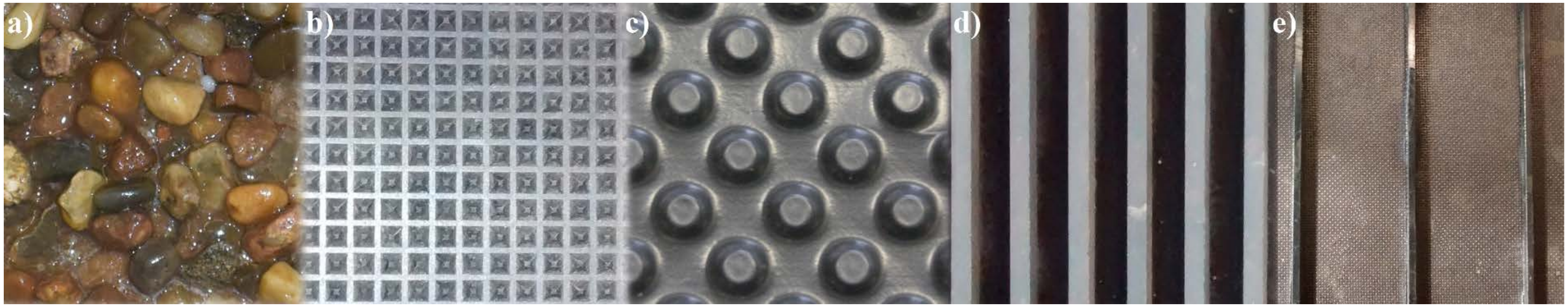
u', w' = Temporal fluctuation of velocity components

$\tilde{u}$, $\tilde{w}$ = Spatial fluctuation of velocity components

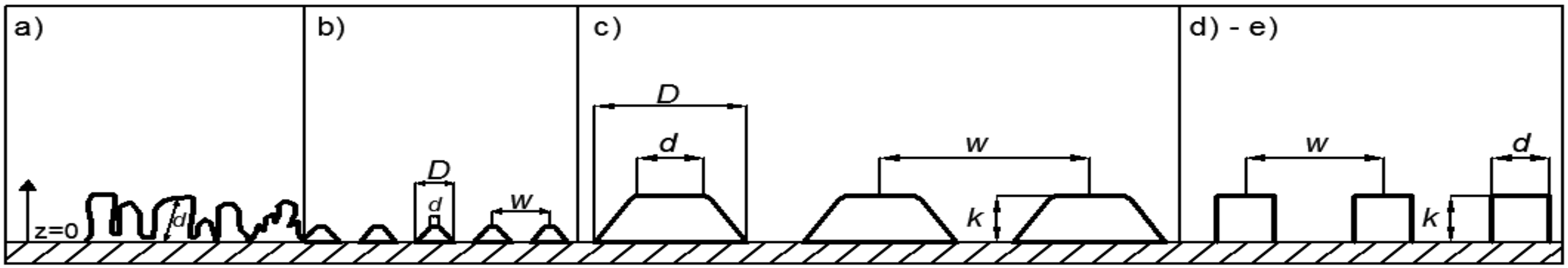
Objectives

- Flow velocity measurements over different surface roughnesses;
- Analysis of data based on DAM methodology;
- Characterization of hydraulically different roughnesses.

Experimental setup



Gravel bed Pyramid Cones Dense bars Wide bars



Surface roughness	k [mm]	d [mm]	D [mm]	w [mm]
Gravel bed		3-6	-	-
Pyramid	2	1	4	6
Cones	6	8	16	25
Dense bars	6	6	-	18
Wide bars	6	6	-	90

k = Geometrical roughness height

d = Smaller side

D = Larger side

w = Spacing

Experimental setup

Flume 6 m long, 0.3 m wide, 0.3 m deep

h_w = 10 cm (water depth)

S_b = 0.001 (bed slope)

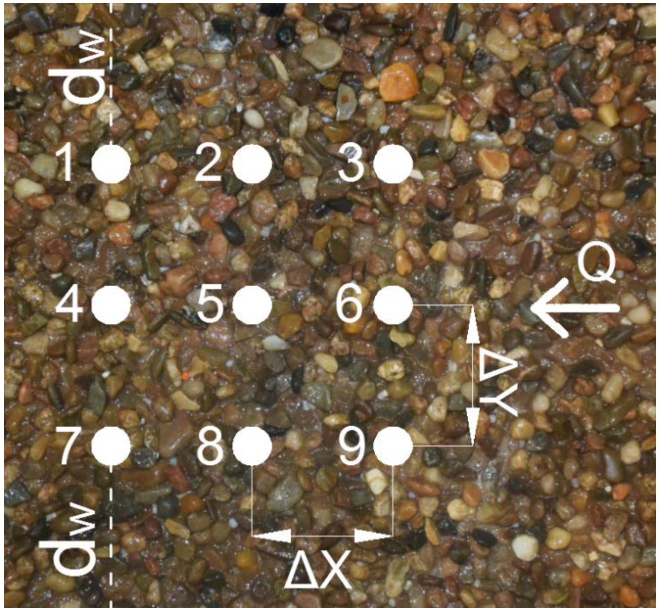
Vectrino profiler

f = 100 Hz (frequency)

T = 60 s (Sampling period)

Methodology

Surface roughness	Wide bars	Gravel bed	Cones	Dense bars	Pyramid
Discharge Q [l/s]	8.5	10.0	10.5	11.5	12.7
Bulk velocity u_m [m/s]	0.28	0.33	0.35	0.38	0.42



d_w = Distance from the wall (13 cm)

ΔX = Longitudinal spacing (2 cm)

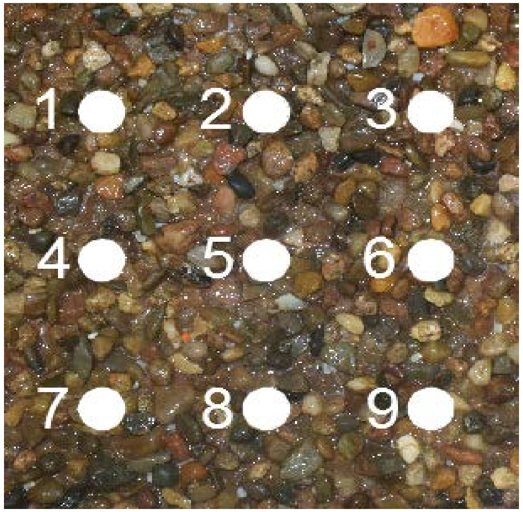
ΔY = Cross section spacing (2 cm)

ΔZ = Vertical measuring spacing (2 mm)

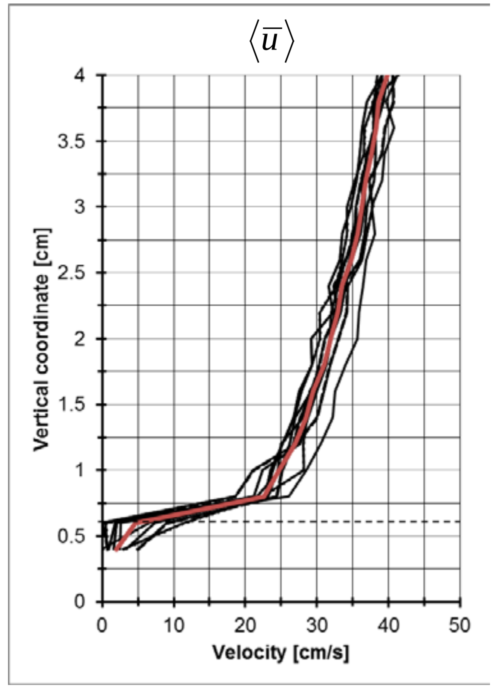
Q = Discharge

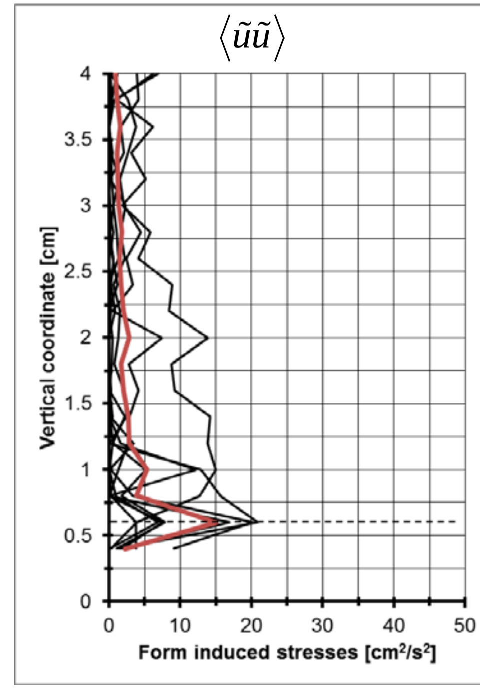
Results

Double averaged velocity



Gravel bed, *k* = 3-6 mm





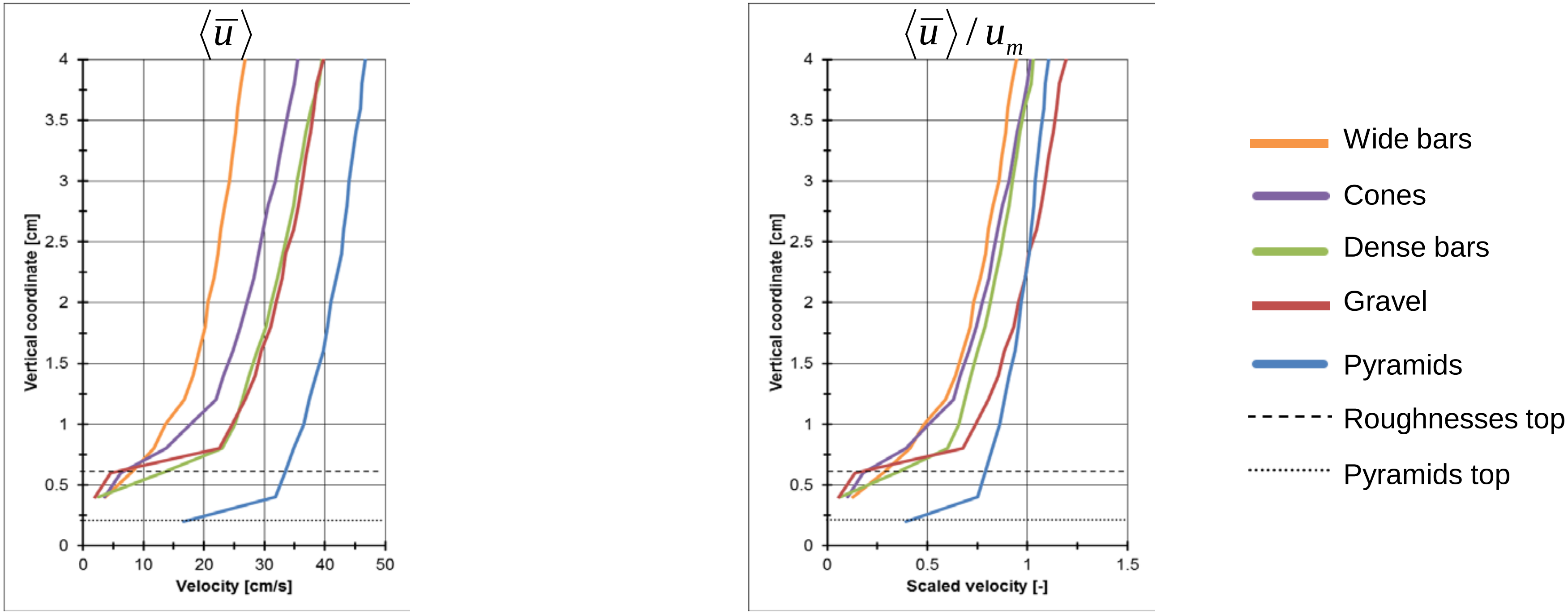
Double averaged profile

Roughness top

Double averaged profiles have not a large difference compared to the time averaged ones.

Results

Double averaged velocity



Highest velocity occurs for Pyramids (elements height).

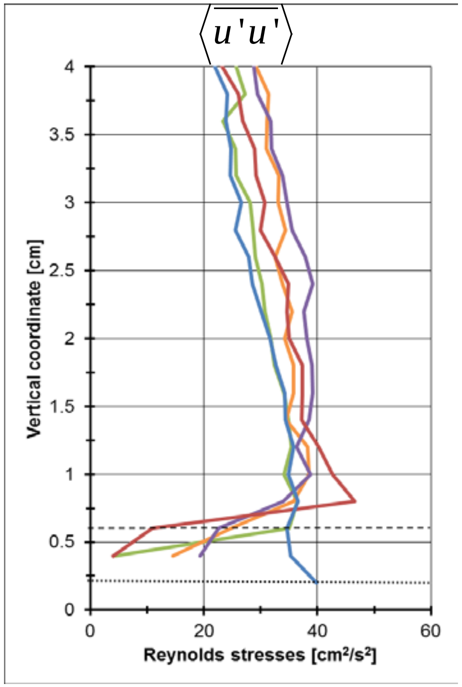
Dense bars and gravels present a similar profile (elements spacing).

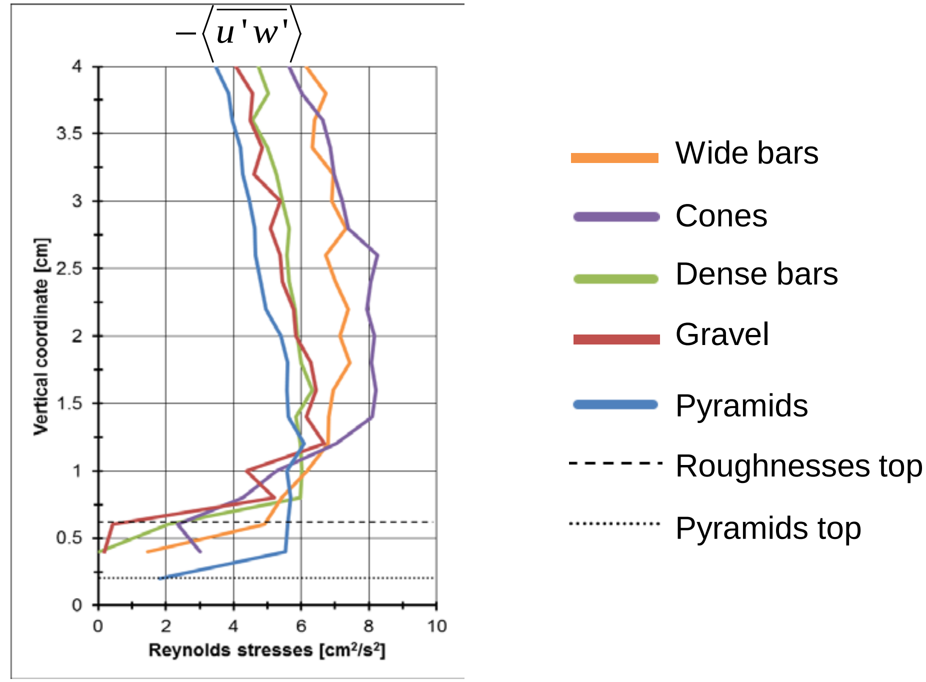
Cones profile is between wide and dense bars (intermediate behaviour).

Pyramids are similar to gravel.

Results

Turbulent stresses





The profiles group together in the linear trend region,

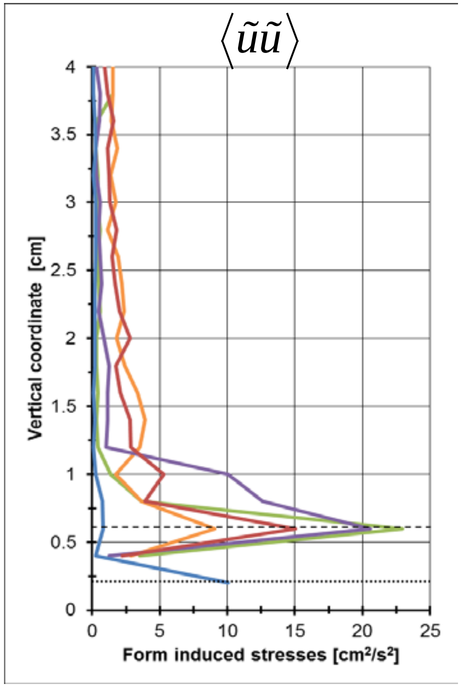
A distinct maximum occurs for the gravel.

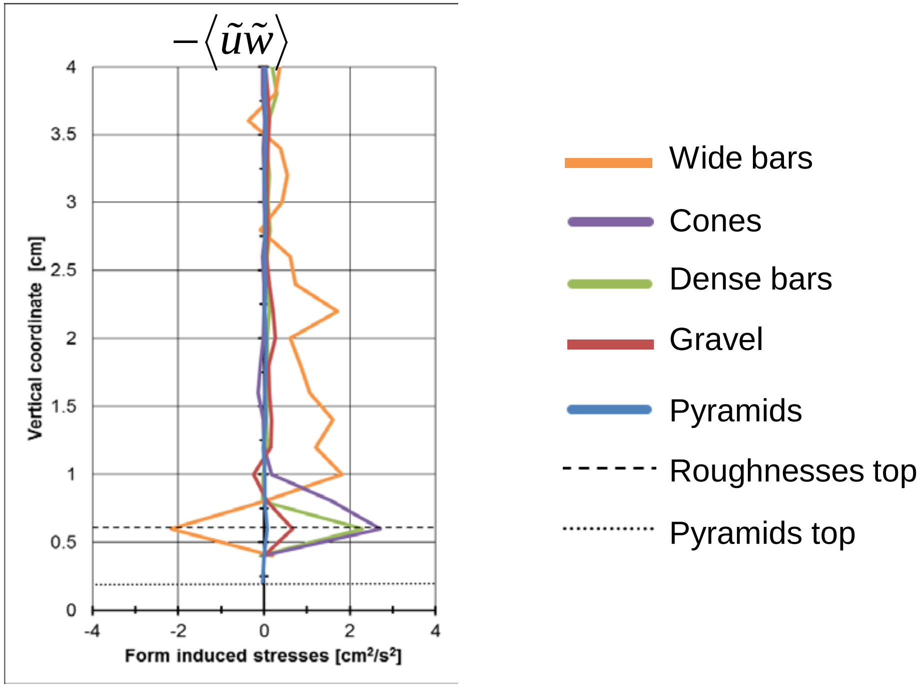
Cones are grouped with wide bars (wider spacing),

Gravel, pyramid and dense bars group together in the linear trend region.

Results

Form induced stresses





The maximum values occur for cones and dense bars.

For cones the values start to increase farther from the bed (elements spacing).

Maximum values occur for cones, dense and wide bars.

Wide bars have negative values (Pokrajac et al., 2007, 2008).

Summary and conclusions

- The lowest flow resistance occurs for pyramids (geometrical height).
- Gravels velocity differs form the other roughnesses (elements height irregularity).
- Reynolds stresses are similar for cones and wide bars (wake interference and isolated obstacles).
- Wide bars have negative form induced stresses (isolated obstacles).
- The studied surface present hydraulic differences.

Thank you for the attention.