Heuristic approach for dynamics of wave-induced currents over an along- shore beach

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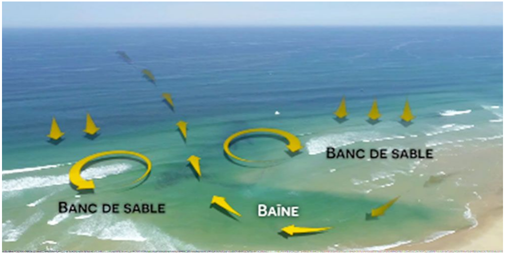
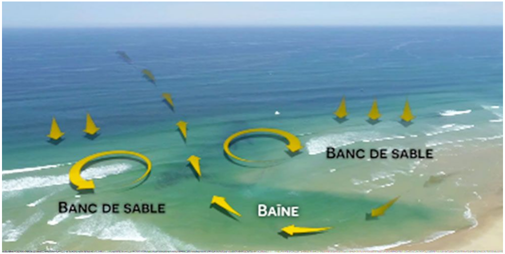
Introduction



A wave-induced current is a strong return current that draws the waters off-shore while these waters are brought by the big waves that break on the beaches.

Introduction



The purpose will be to determine what is the minimal model to simulate a baine with a very simplified approach. We won't consider waves.
We will consider a 2D approach with a section of the beach. Let's define the steps that we will follow :

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Purpose

- In this section we aim to determine geometrical conditions that must be fulfilled to obtain significant rip currents. We will work on a 2D case.
- In order to study a monophasic phenomena we will study the impact of simple obstacles on a inlet Blasius flow parallel to the alongshore beach

Order Analysis

- From Navier-Stockes equations we can give a simple estimate of the thickness of the viscous boundary layer.

$$\left\{ \begin{array}{l} u(x, y = \delta) = U_0 \\ u(x, y = 0) = 0 \end{array} \right. \tag{1}$$

- Under assumptions that $\frac{\partial p}{\partial y} << 1$ and with the pressure evaluated to infinity of the beach p_∞, we obtain the following result :

$$\left\{ \begin{array}{l} \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \\ u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \nu\frac{\partial^2 u}{\partial y^2} - \frac{1}{\rho}\frac{dp_\infty}{dx} \end{array} \right. \tag{2}$$

Order Analysis

- The conservation equation of mass implies $v = \frac{\delta}{x} U_\infty$, and thus from the conservation equation of momentum we obtain:
$\frac{U_\infty^2}{x} \sim \nu \frac{U_\infty}{\delta^2} \Rightarrow \delta \sim \frac{x}{{R_{ex}}^{\frac{1}{2}}}$ with $R_{ex} = \frac{U_\infty x}{\nu}$
- It can be shown that the Blasius solution implies that the friction coefficient is $Cf_x = 0.664 {R_{ex}}^{-\frac{1}{2}}$ and by definition
$Cf_x = 2 \frac{\nu}{U_\infty \delta} = 2 {R_{ex}}^{-1} \frac{x}{\delta}$
Thus $0.664 {R_{ex}}^{-\frac{1}{2}} = 2 {R_{ex}}^{-1} \frac{x}{\delta}$ and
$\delta = 2 \frac{x}{0.664 {R_x}^{\frac{1}{2}}} = \frac{x}{0.332 R_{ex}} = \frac{\sqrt{x}\sqrt{\nu}}{0.332 U_\infty}$

Blasius profil

- On the inlet side we generate a velocity flow from a polynomial function of order 2 with $\eta = \frac{y}{\delta}$.

$$\frac{u(\eta)}{U_\infty} = \begin{cases} a\eta^2 + b\eta + c, \forall 0 \leq \eta \leq 1 \\ 1, \forall \eta \geq 1 \end{cases} \quad (3)$$

- (2) $\Rightarrow u(\eta = 0) = 0 \Rightarrow c = 0$ and $u(\eta = 1) = 1 \Rightarrow a + b = 1$.
  Moreover, the free surface condition involved $\frac{du}{d\eta}(\eta = 1) = 1 \iff 2a + b = 1$.
  Thus, $\begin{cases} a = -1 \\ b = 2 \end{cases}$ and $u(\eta) = 2\eta - \eta^2, \forall 0 \leq \eta \leq 1$

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Nondimensionalization

This is Sitges and not Boscombe

Field measurements have been gathered from drifter deployments from Boscombe beach. It is a beach with several groynes, like Sitges. The maximum longshore velocity is about $U_\infty = 0.5 m \cdot s^{-1}$. The mean surf zone width is $X_b = 50 m$. Thus as Reynolds number can be chose as $R_e = \frac{.5 \times 50}{1} = 25$. By choosing the scales of references as $U^\star_\infty = 1, X^\star_g = 1$ we can work with $\nu^\star = 0.04$.

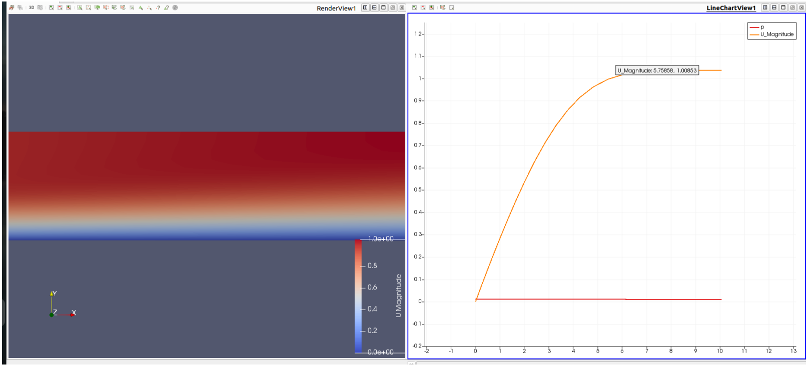
Boundary conditions

- We take the following boundary conditions in our domain.

Boundary	Value for the velocity field	Value for the pressure field
inlet	$u^\star(\eta) = 2\eta - \eta^2$	zeroGradient
outlet	zeroGradient	uniform 0
Bottom	noSlip	zeroGradient
top	zeroGradient	zeroGradient

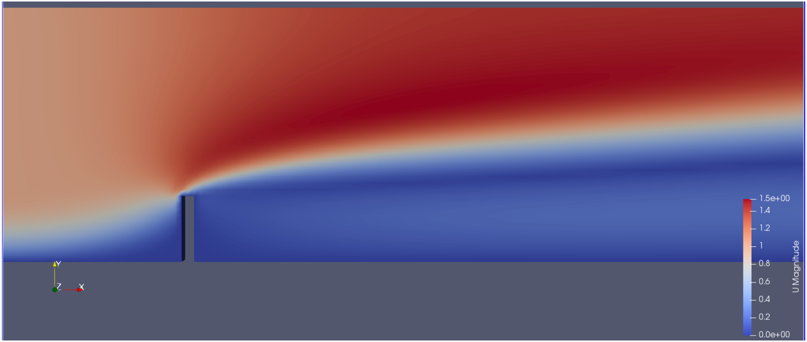
Test Case

2D Blasius flow, the flow calculated represented the currents over an alongshore beach. On the right side we represent the velocity field profil, it shows as expected, as Blasius courbure



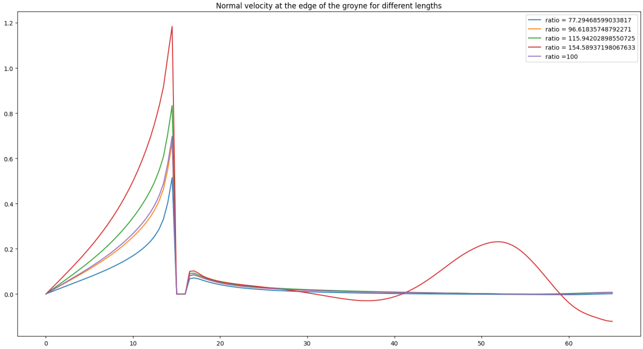
One obstacle

Let us oppose an obstacle to the flow of Blasius.



One obstacle

Let us oppose an obstacle to the flow of Blasius. Normal component of the velocity field at the edges of the groynes. We observe that the bigger $\frac{L_g}{\delta}$ is, the bigger is the normal velocity. Indeed the section is reduced as the groyne is bigger and the velocity is expected to grow according to Bernoulli equation.



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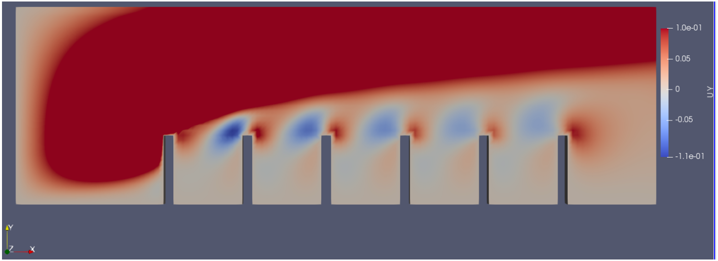
Lenght of the groynes	pourcentage of the thickness boundary layer (%)
4	72.49
5	90.61
5.175	100
6	108.74
8	144.99

Several obstacles

We set several groynes with regular spacing and observe the normal velocity over a line at the edge for several choices of length. The flow is coming from the left and the first groyne is at position 15.



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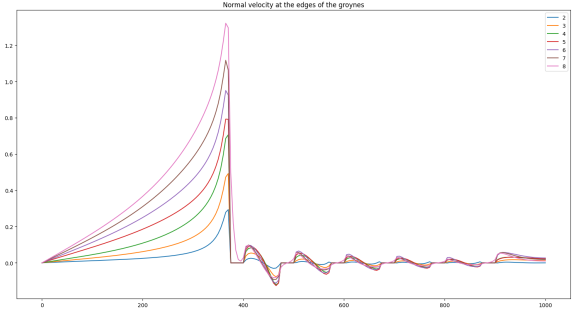


Several obstacles

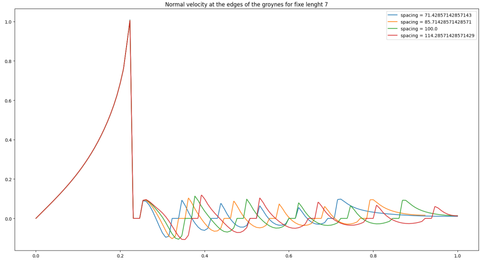
We set several groynes with regular spacing and observe the normal velocity over a line at the edge for several choices of length. The flow is coming from the left and the first groyne is at position 15.

Spacing	pourcentage of the thickness boundary layer (%)
2	36.24
3	54.37
4	72.59
5	90.619
6	108.74
7	126.86
8	144.99

We observe that between the groynes the velocity is positive on the left part and negative on the rigth part. The bigger the groynes are compared to the thickness of the boundary layer , the bigger is the normal component of the velocity. 7

Several obstacles

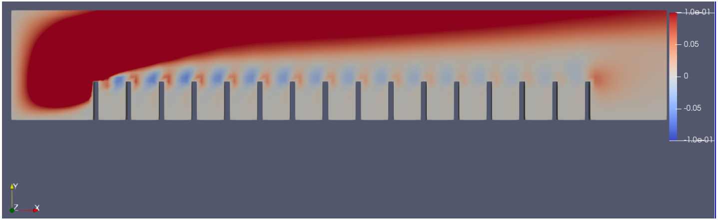
Impact of the ratio between the length of the groynes and the spacing.
We tried to spot different regimes by running several simulations with a fixed length groyne of 7 and different values for the spacing. It seems that the rip current increases with the spacing between the groynes.



Spacing X_g	ratio $\frac{X_g}{L_g}$ %
5	71.4285
6	85.714
7	100.0
8	114.285

Several obstacles

Impact of the ratio between the length of the groynes and the spacing.
In order to have a better distinction of the curves we also ran a simulation with 16 groynes. Here we visualise the normal component of the velocity field which has been re-scaled.



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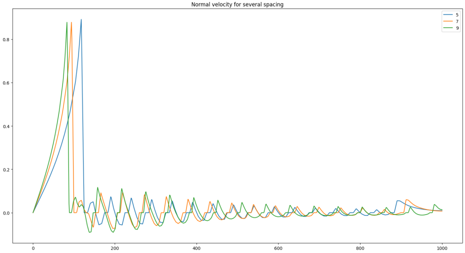

Spacing X_g	ratio $\frac{X_g}{L_g}$ %
5	71.4285
7	100.0
8	128.571

The end

Thank You