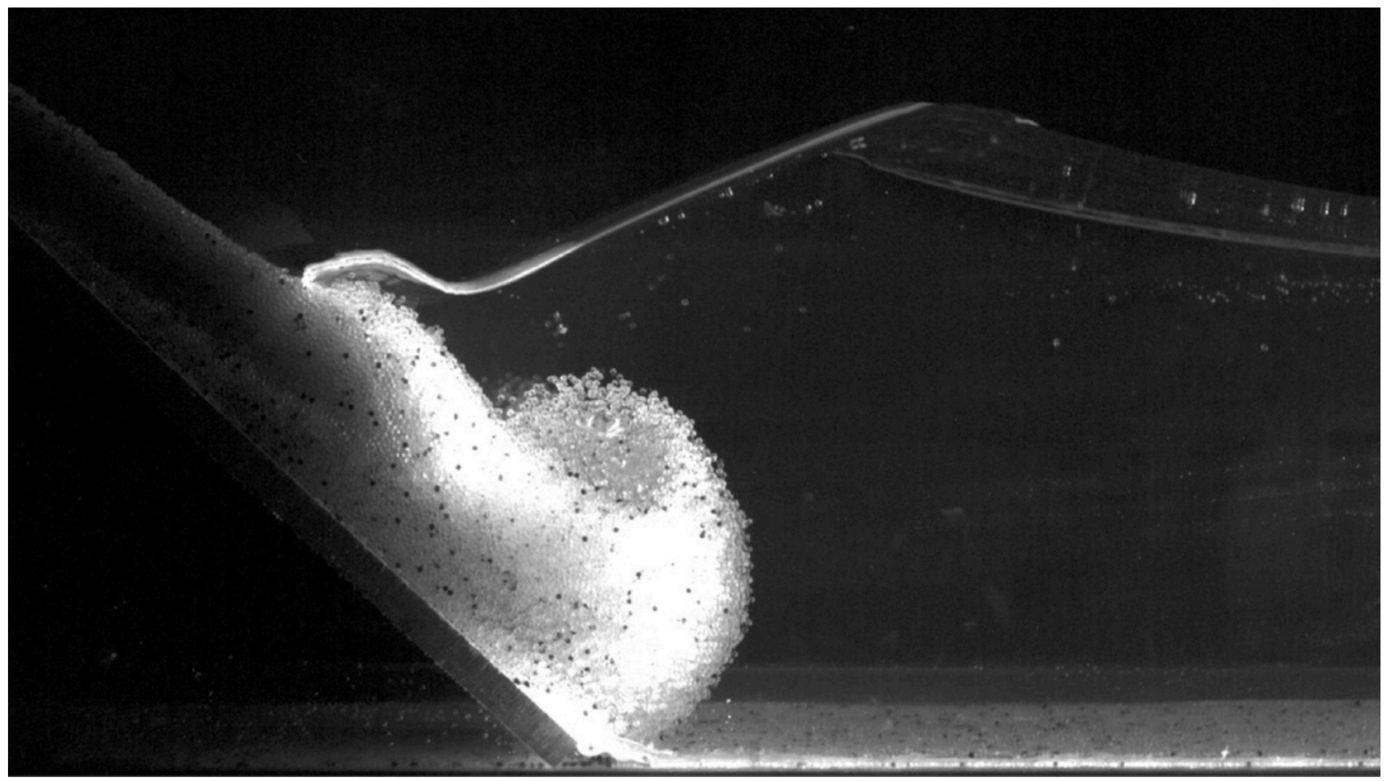
# Tsunami waves generated by subaerial landslide



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# Specificity of landslide induced tsunamis (compare to submarine earthquake)

## Could be **locally** more dangerous

Generation occurs close to the coasts or in lakes

## Generation processes are more complex

Interactions between the slide and the waves

## Strong dispersive and non-linear effects

Wavelengths much shorter than tsunamis generated by earthquakes

Rarely trans-oceanic (local effects)

## Generation of « mega-tsunamis »

Wave amplitude directly linked to the properties of the slide

Lituya Bay, Alaska, 1958 → runup 524 m !

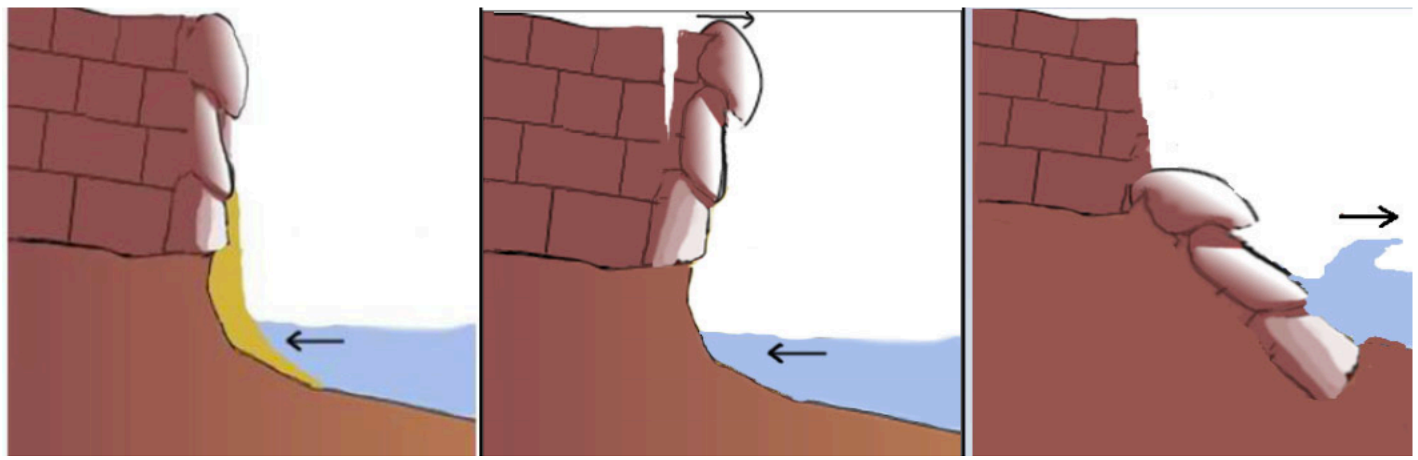

Global Times

USGS

# 3 types of subaerial landslides

## **Rockfall**

usually associated with nearly vertical slopes. Only more resistant rock can sustain these angles on the coast.  They are most commonly triggered by undercutting in the inter-tidal zone or freeze-thaw weathering.



Averbukh *et al.*, Est. J. Eng., 2013

Somewhere North of France (Youtube)

# 3 types of subaerial landslides

## Earth Flows

The slope material liquifies and runs out, forming a bowl or depression at the head. The flow itself is elongated and usually occurs in fine-grained materials or clay-bearing rocks on moderate slopes and under saturated conditions. However, dry flows of granular material are also possible.

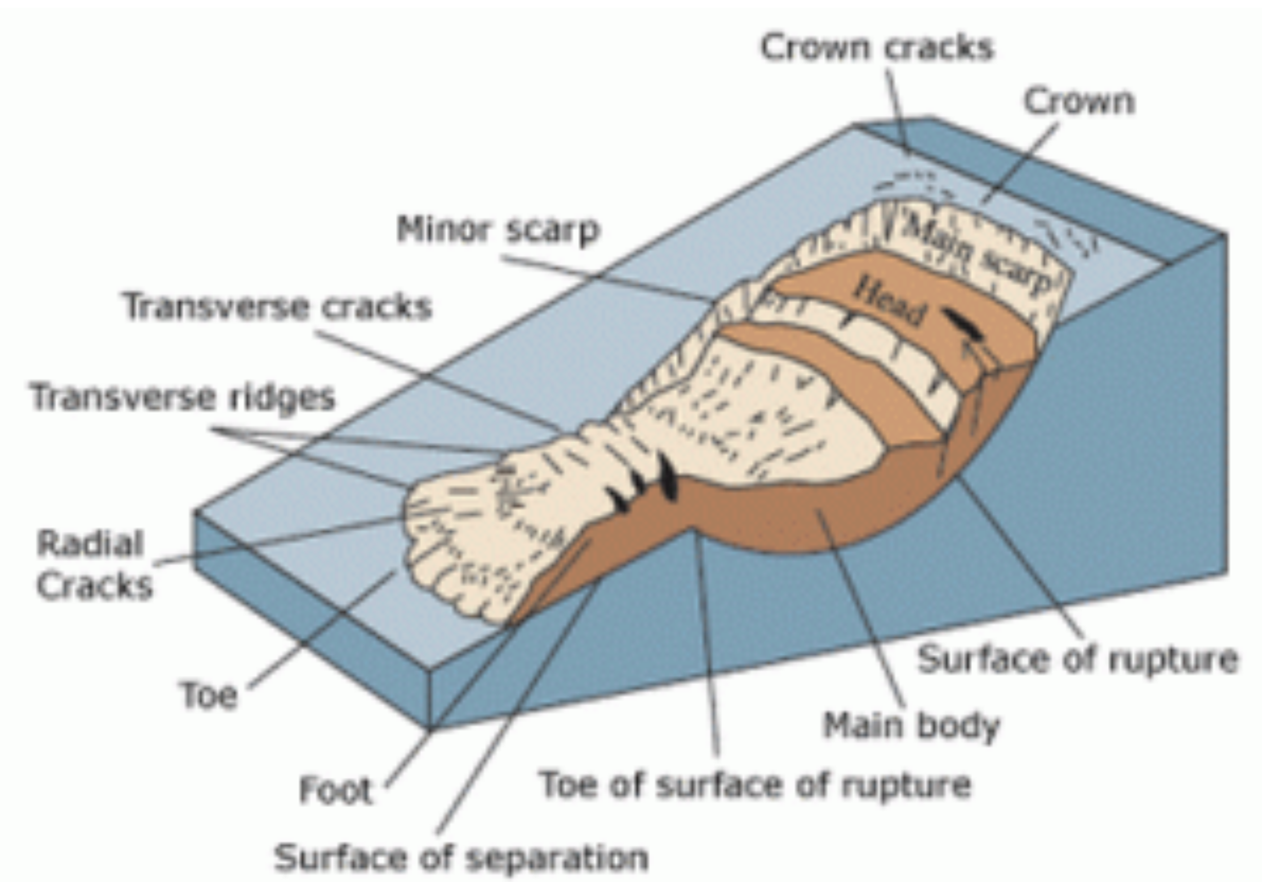
source Tages Anzeiger

Soufrière volcano (Montserrat)

# 3 Types of subaerial landslides

## Slumps

Marine processes erode and undermine the base of the cliff. Rainwater infiltrates the cliff through unconsolidated, porous material (e.g. boulder clay). This then creates a slip plane. The weight of the saturated clay causes the material to slump along the slip plane.




Source NationalAtlas.gov

Youtube : WorldMostShocking Natural disasters

# Imposing initial free-surface deformation (from subaerial landslide)

Walder et al., JGR, 2003

**TOPICS**
Tsunami Open and Progressive Initial Conditions System

- Laboratory experiments using a solid block
- Initial deformation of the free-surface directly imposed from numerous experimental measurements

$$\eta(x) \sim \eta_0 \mathrm{sech}^2(x/\lambda_0)$$

$$\eta_0 \sim 1.32\, h \left( \frac{t_s \sqrt{gh^3}}{V_w} \right)^{-0.68}$$

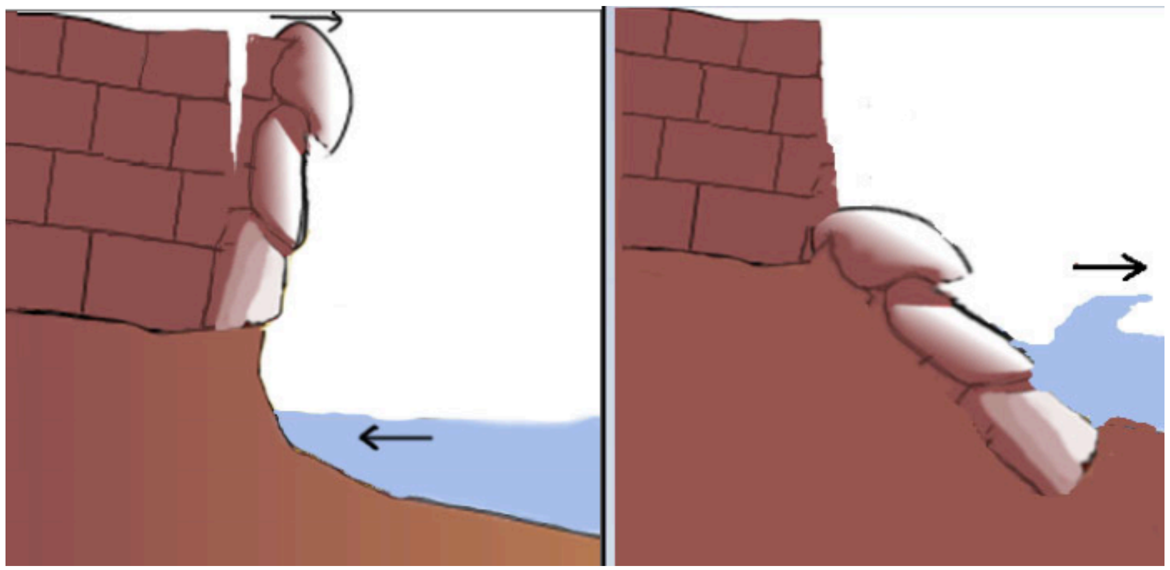
$$\lambda_0 \sim 0.27\, t_s \sqrt{gh}$$

$$\eta(x,y) = (wV_w/4\lambda_0^2)\mathrm{sech}^2(x/\lambda_0)\mathrm{sech}^2(y/\lambda_0)$$

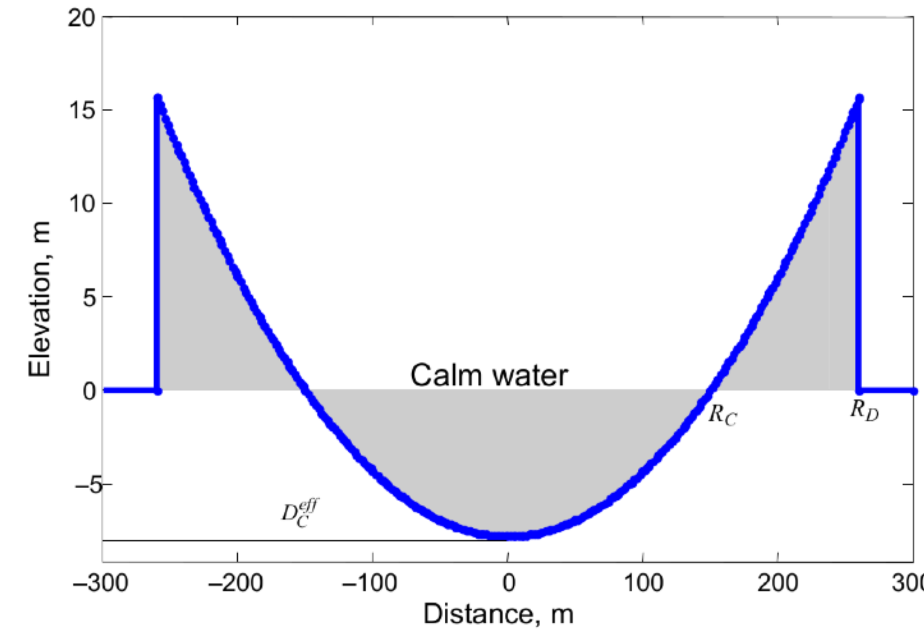
(In Gerris but not in Basilisk)

$$\eta(x,y) = \eta_0 \mathrm{sech}^2(x/\lambda_0)\mathrm{sech}^2(y/\sigma)$$

# Generation by rockfall



Approximated by a solid block impacting vertically




From Averbukh *et al.*, Est. J. Eng., 2013

$$\eta(r,0) = \begin{cases} D_C\left(\frac{r^2}{R_C^2} - 1\right), & \text{si} \quad r \leq R_D \\ 0, & \text{si} \quad r > R_D \end{cases}$$

$$R_C = R_i \left(\frac{2\epsilon\rho_i v_i^2}{\rho_w g R_i}\right)^{\delta} \left(\frac{1}{q R_i^{\alpha-1}}\right)^{2\delta}$$

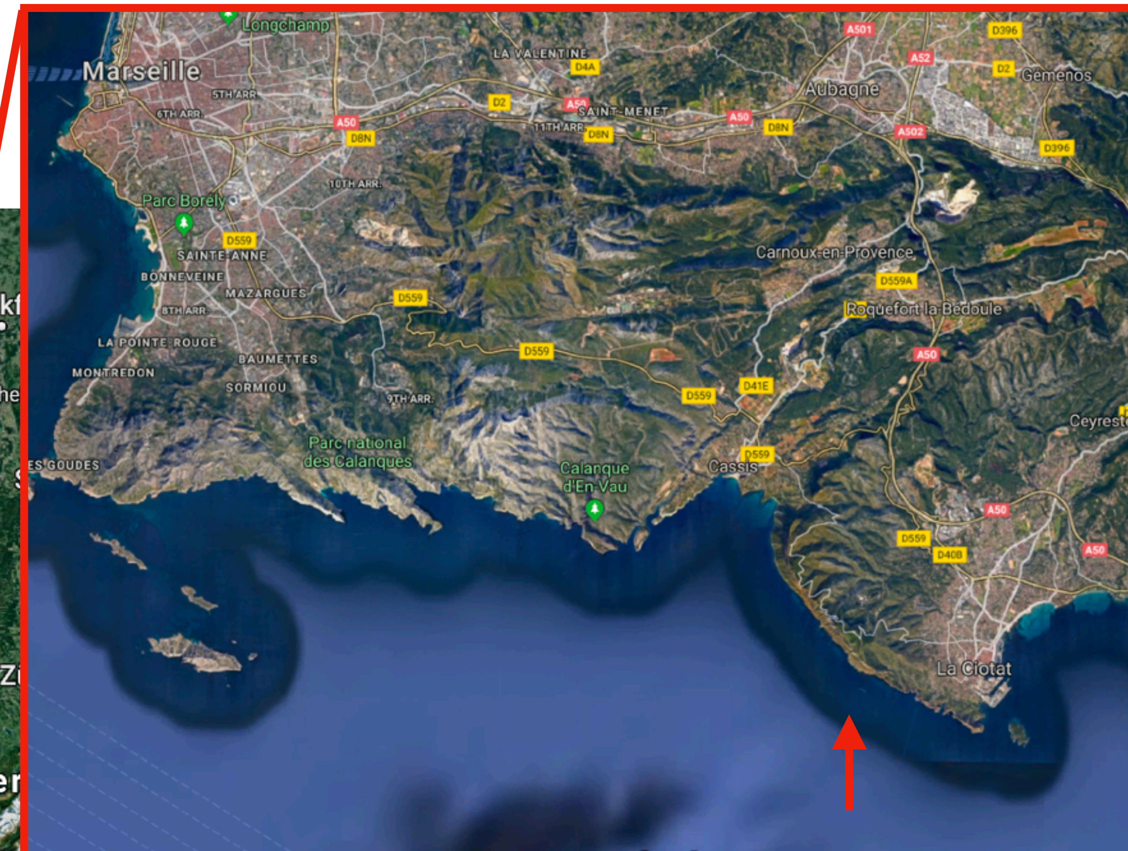
α, δ, ε et q = constants

$$R_D = \sqrt{3} R_C$$

$R_i, \rho_i, v_i$ = radius, density and impact velocity of the block

$$D_C = \sqrt{\frac{2\epsilon\rho_i R_i^3 v_i^2}{\rho_w g R_C^2}}$$

# Case study : Cap Canaille (Cassis, France)

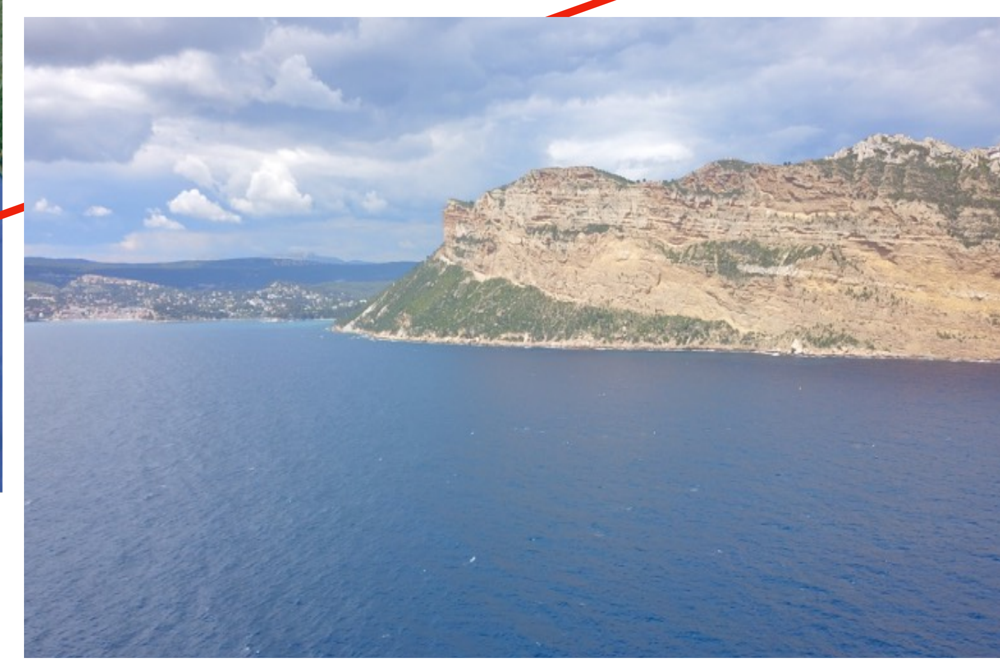



Photo : Augustin Barennes

# Generation by rockfall

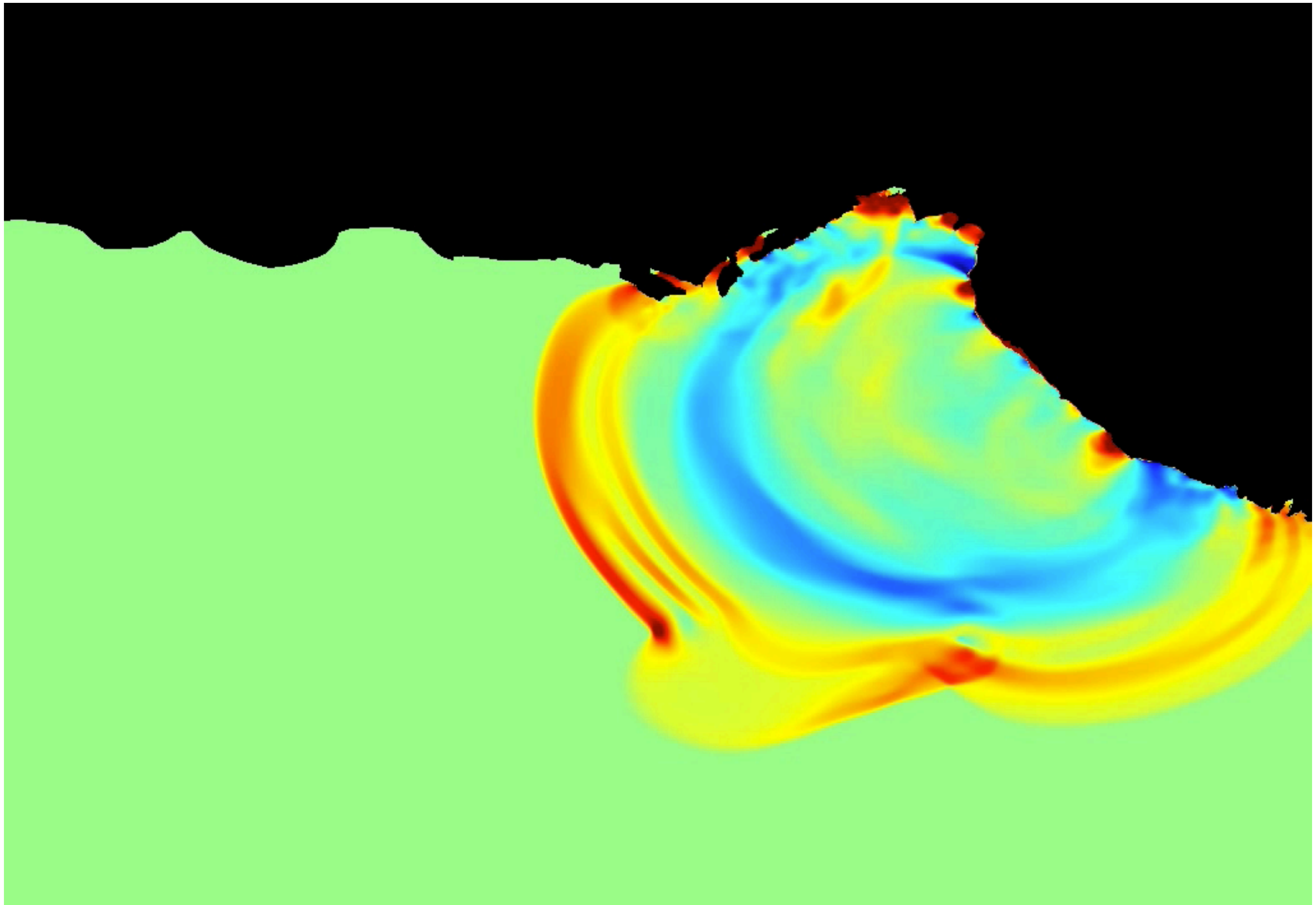
4 Impactors : - radius : 30m
- density : 2000 kg/m$^3$
- impact velocity : 50 m/s
- water depth at impact : 40 m

Basilisk : - spherical.h, saint-venant.h, terrain.h
- terrain : EMODnet + Litto3D

foreach(){

$$\text{hpert}\{\} = \begin{cases} D_C\left(\frac{r^2}{R_C^2} - 1\right), & \text{si} \quad r \leq R_D \\ 0, & \text{si} \quad r > R_D \end{cases}$$

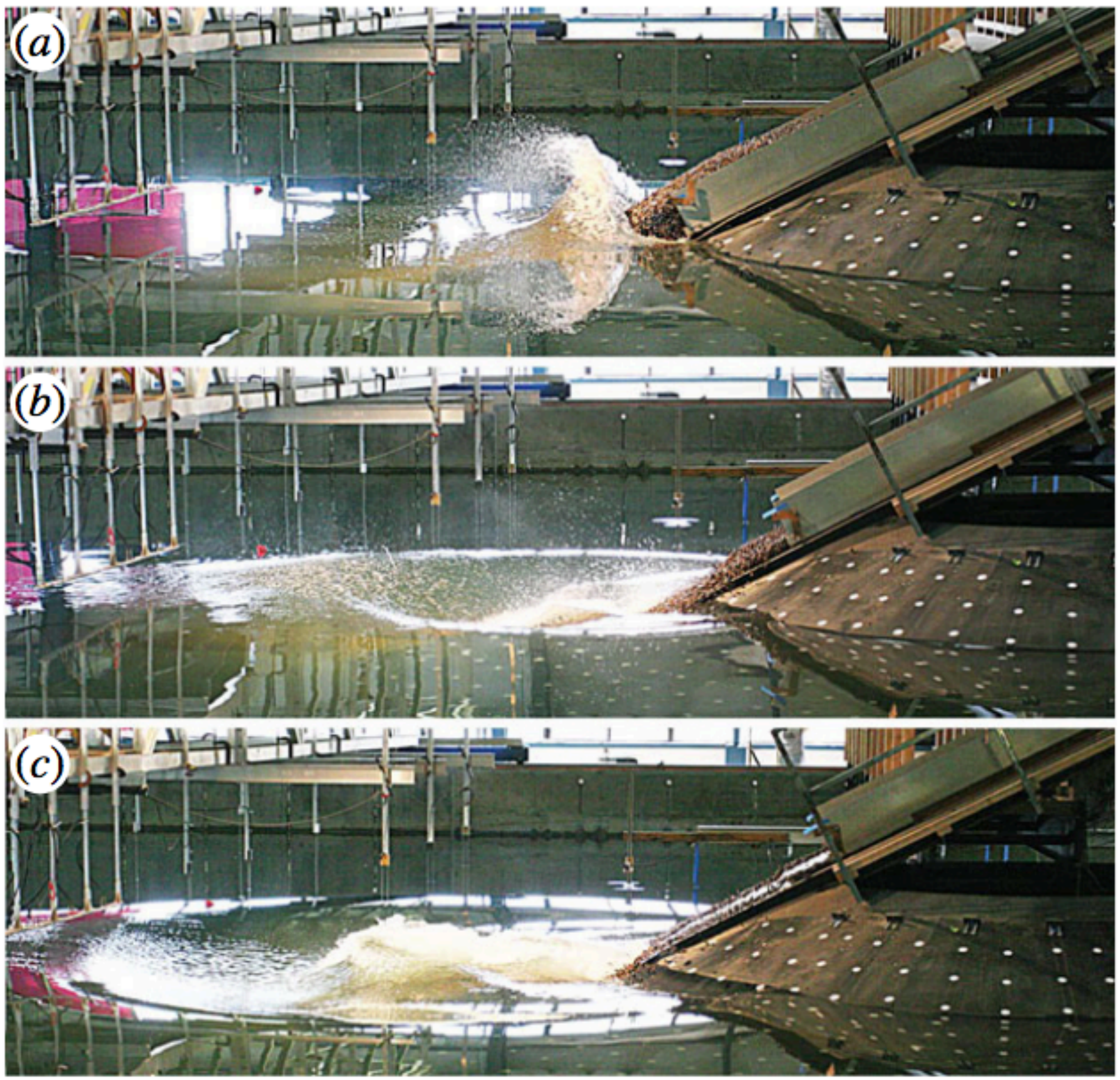
}

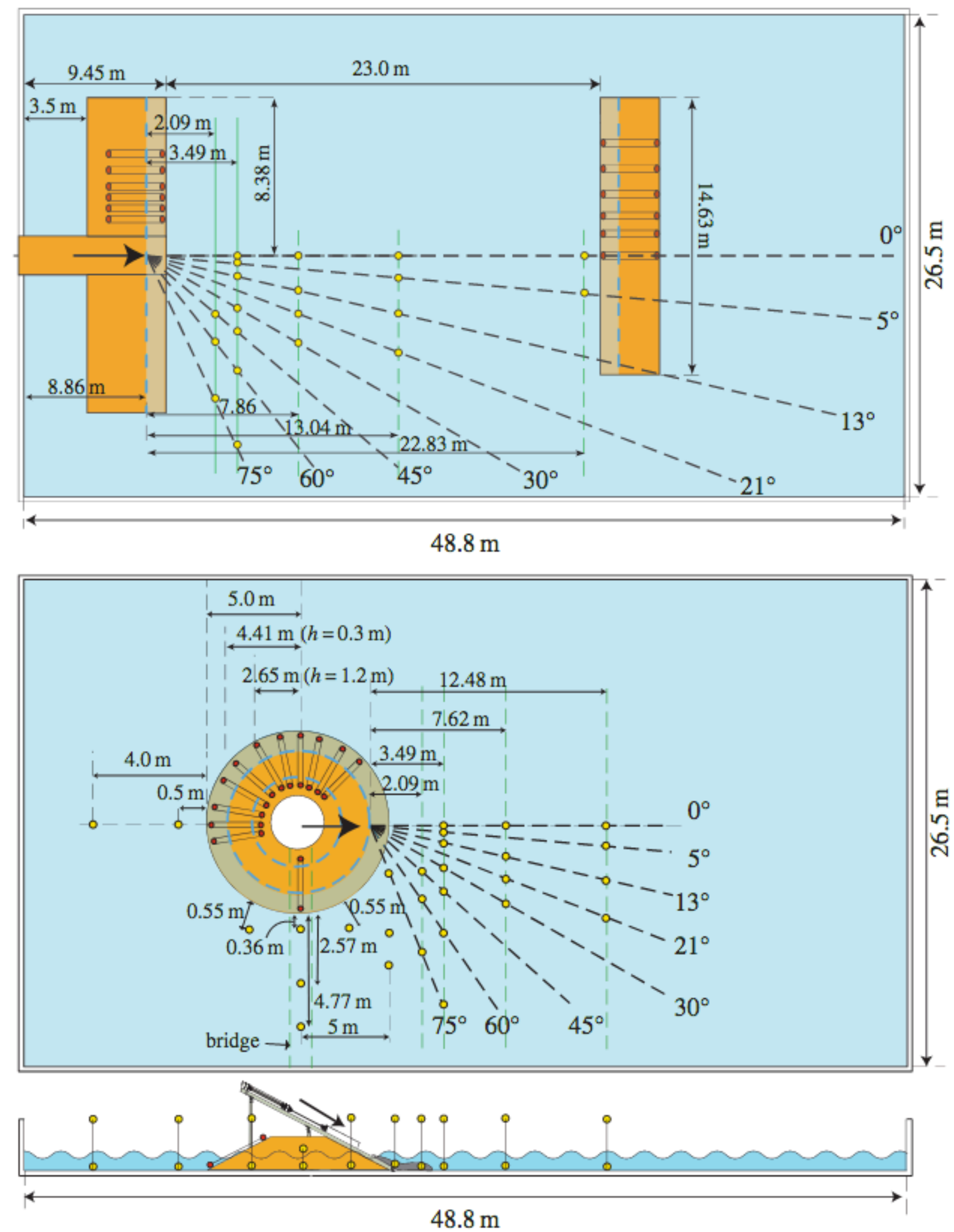


# Generation by Earth flow

B. C. McFall and H. M. Fritz, Proc. R. Soc. A, 2016

Large scale experiments using deformable granular slide



# Generation by Earth flow

B. C. McFall and H. M. Fritz, Proc. R. Soc. A, 2016

Impact velocity $\longrightarrow$ $$Fr = \frac{v_s}{\sqrt{gh}}$$

Thickness of the slide $\longrightarrow$ $$S = \frac{s}{h}$$

Length of the slide $\longrightarrow$ $$L = \frac{L_s}{h}$$

Width of the slide $\longrightarrow$ $$B = \frac{b}{h}$$

Volume of the slide $\longrightarrow$ $$V = \frac{V_s}{h^3}$$

# Generation by Earth flow

B. C. McFall and H. M. Fritz, Proc. R. Soc. A, 2016

$$a_{c1} = h\,0.31F^{2.1}S^{0.6}\left(\frac{r}{h}\right)^{-1.2F^{0.25}S^{-0.02}B^{-0.33}}\cos\theta$$

Amplitude 1st crest

$$a_{t1} = h\,0.7F^{0.6}S^{0.55}L^{-0.2}\left(\frac{r}{h}\right)^{-1.3F^{-0.3}B^{-0.02}L^{-0.2}}\cos\theta$$

Amplitude 1st trough

$$a_{c2} = h\,0.9F^{0.7}S^{0.6}B^{-1}L^{-0.5}\left(\frac{r}{h}\right)^{-1.7F^{-1}B^{-0.2}L^{-0.4}}\cos^2\theta$$

Amplitude 2nd crest

$$\lambda_1 = h\,4.3F^{0.22}S^{0.06}L^{0.03}\left(\frac{r}{h}\right)^{0.3}$$

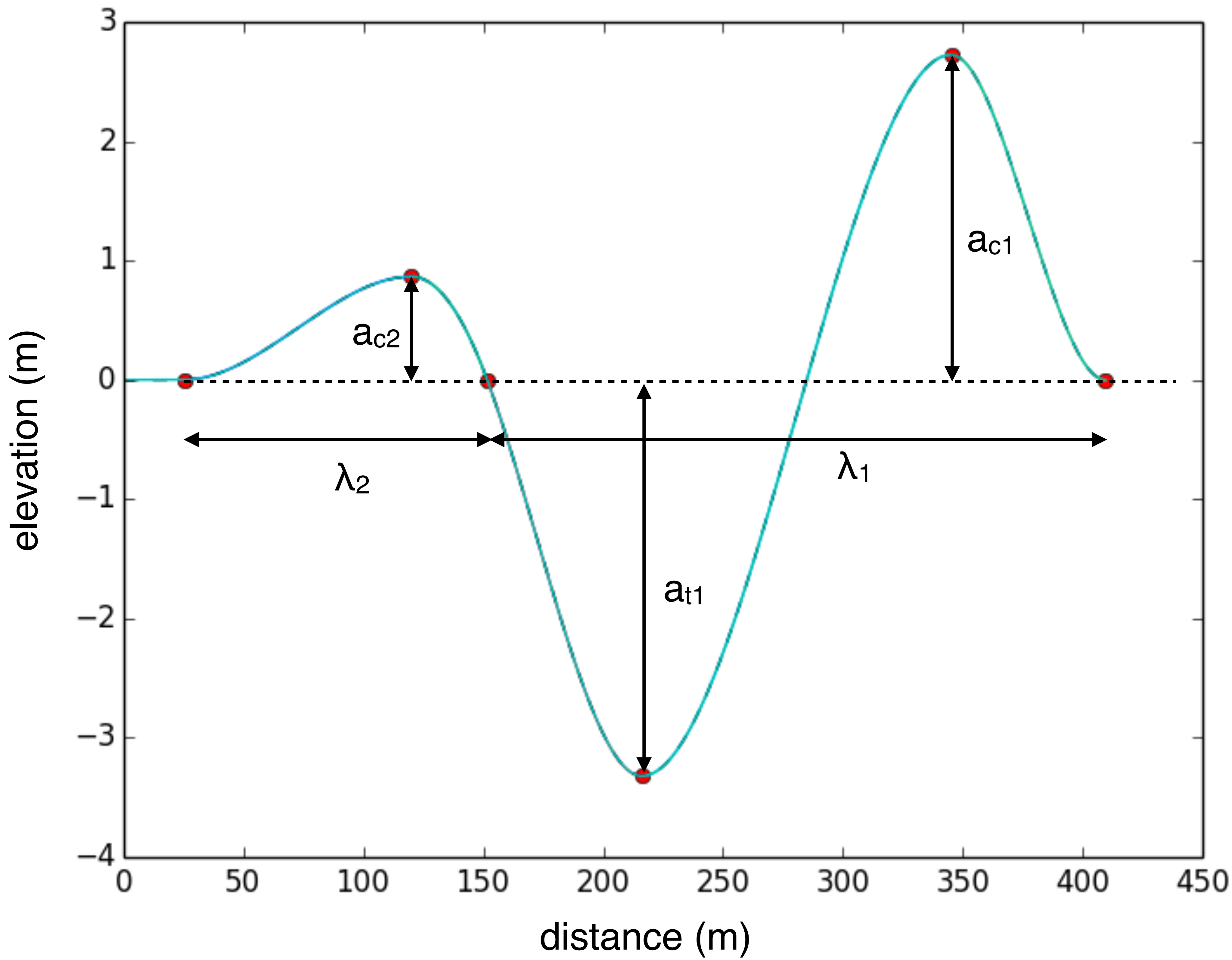
Wavelength 1st wave

$$\lambda_2 = h\,2.0F^{0.22}S^{0.04}L^{0.07}\left(\frac{r}{h}\right)^{0.25}$$

Wavelength 2nd wave

# Generation by Earth flow

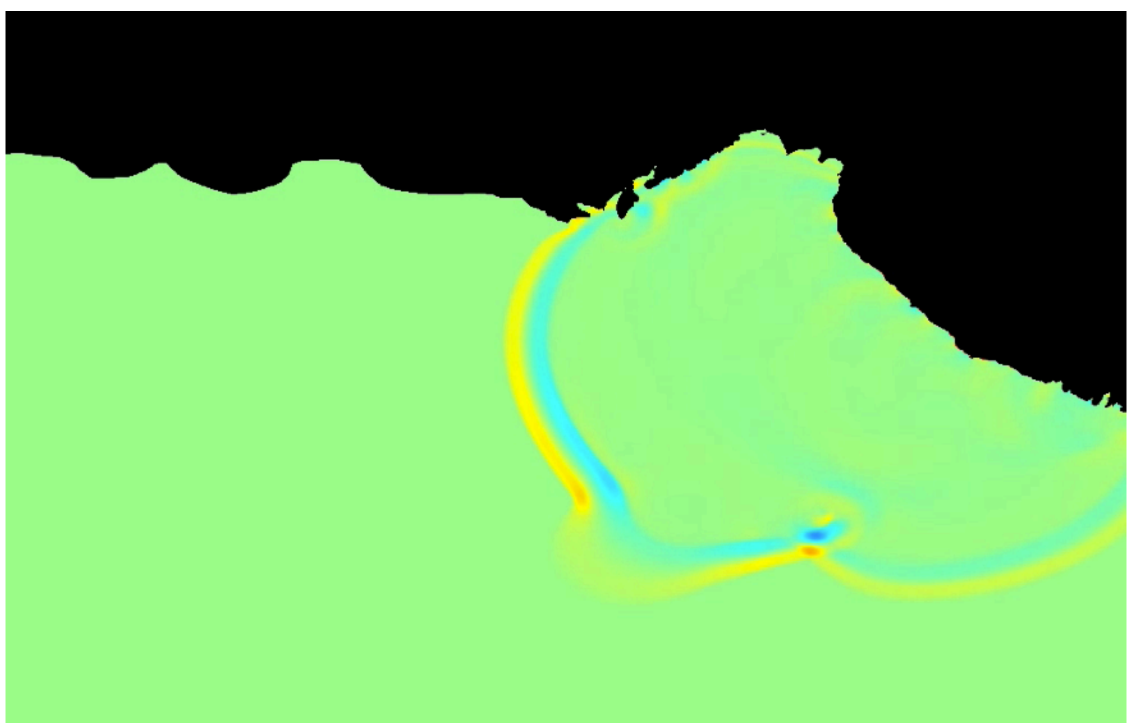
« Multi-cubic » fit to obtain an initial deformation of the free-surface



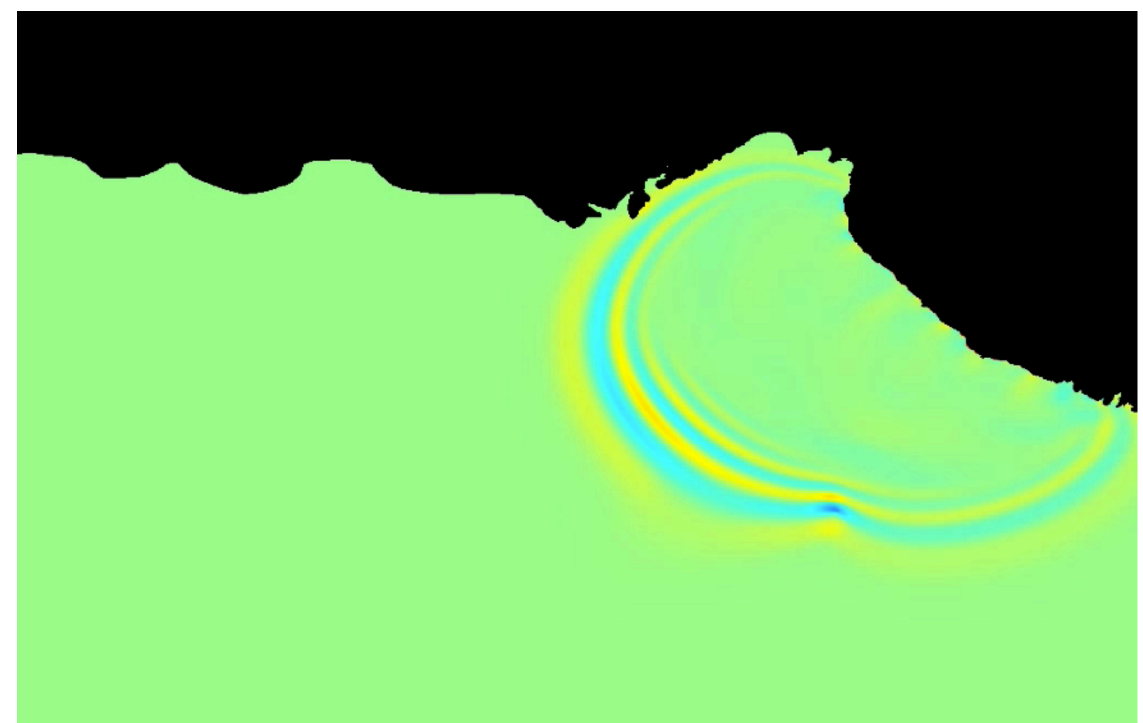
# Generation by Earth flow

- slide velocity : 40 m/s
- slide thickness : 15 m
- slide width : 250 m
- slide volume : 1.0e$^{6}$ m$^{3}$
- slide direction : 225
- water depth at impact : 40 m

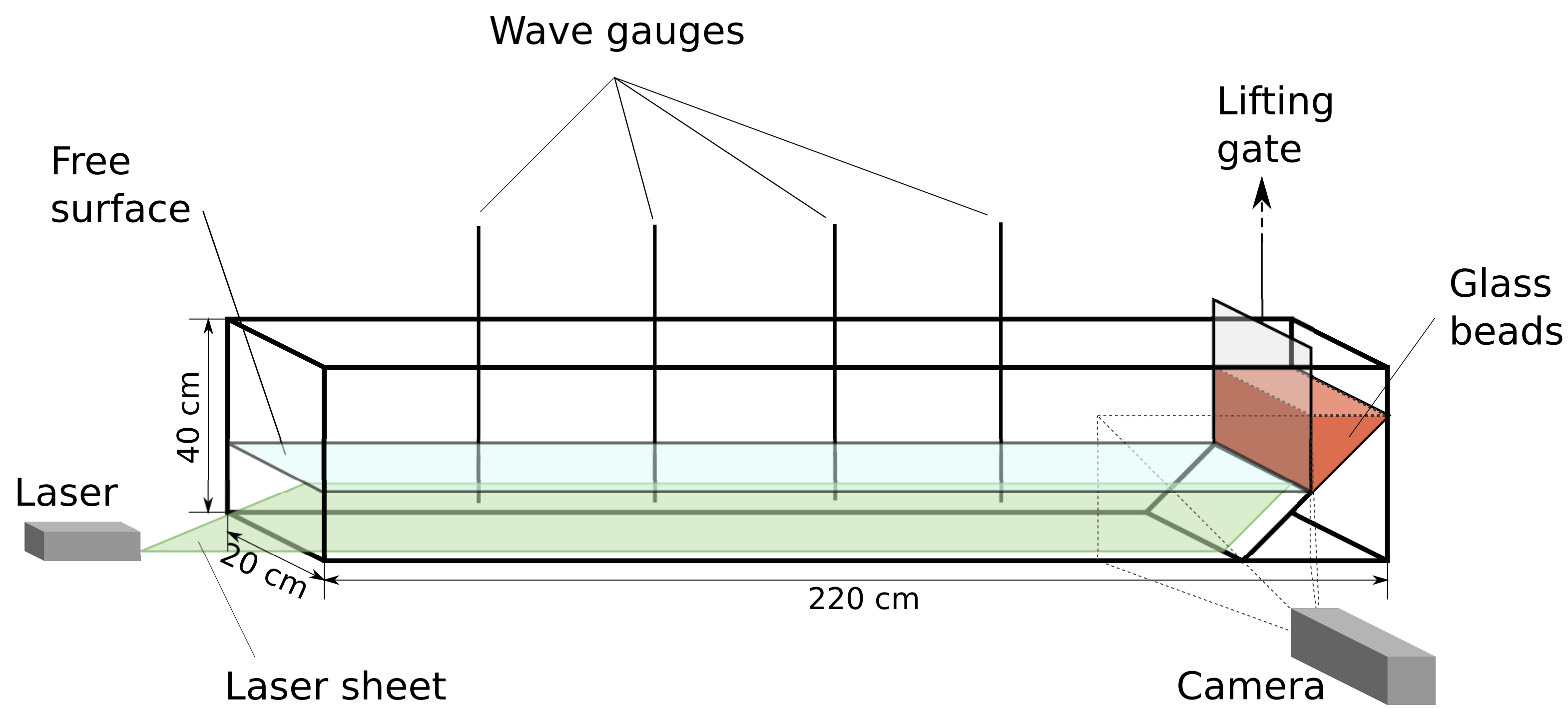
**saint-venant.h**

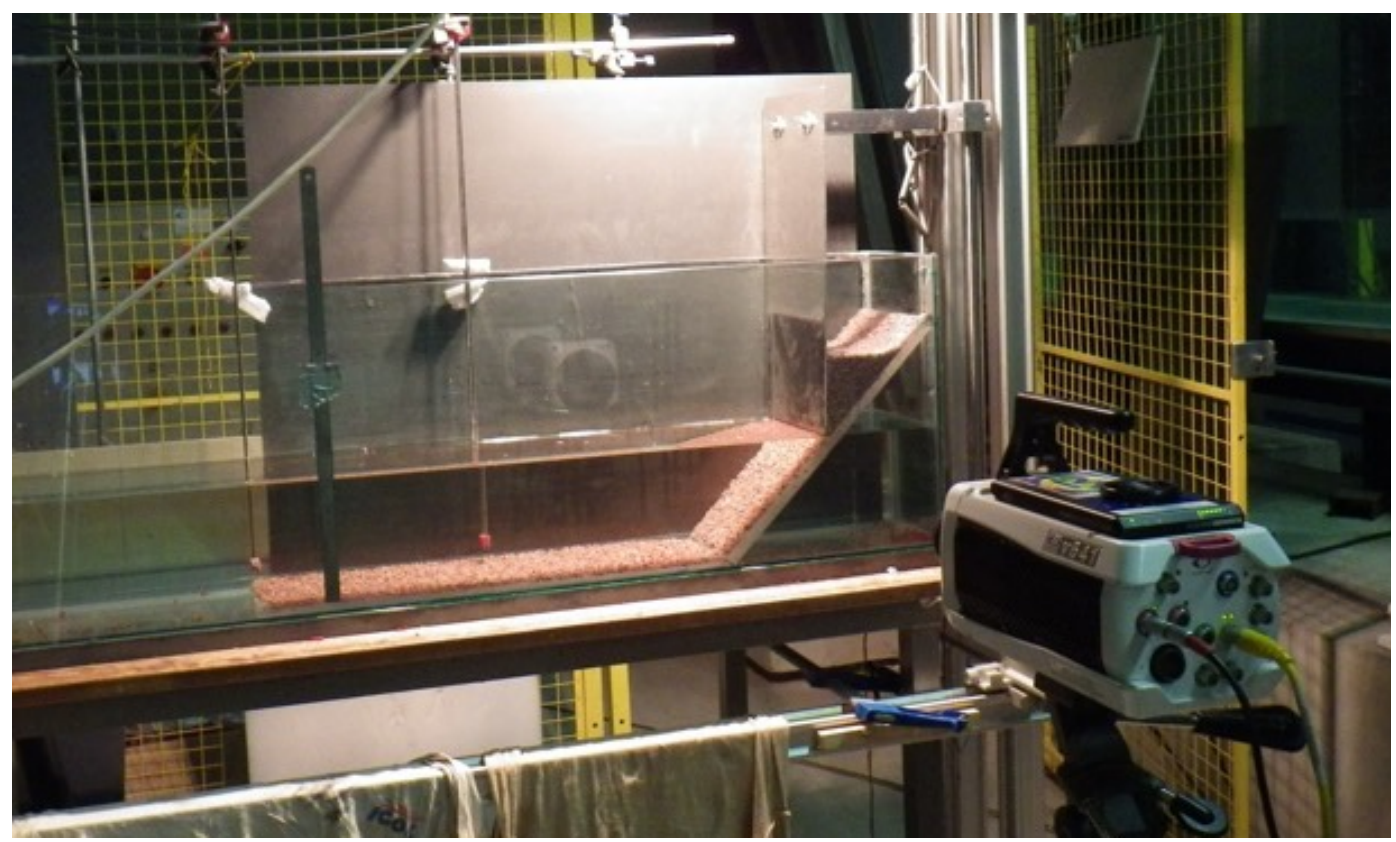


**green-naghdi.h**



# Generation by slump

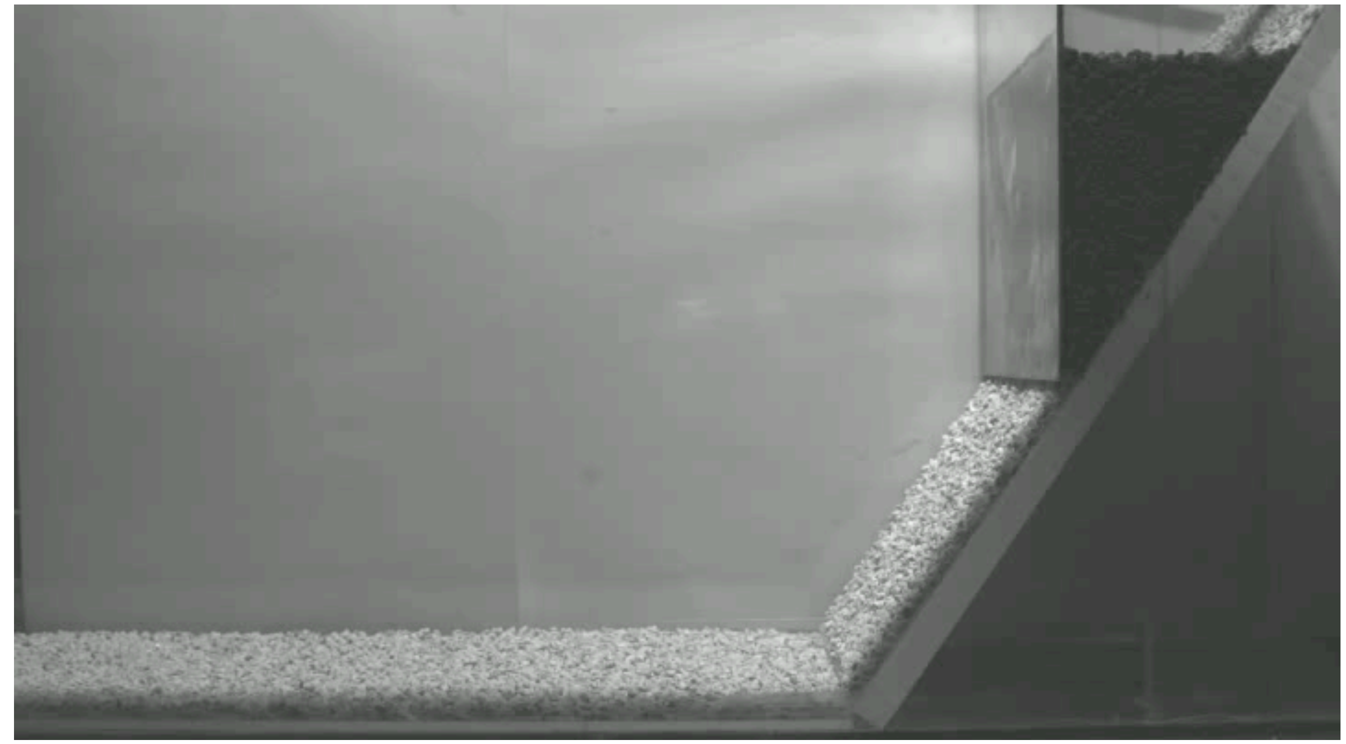



Glass beads, d = 1.5, 4 et 10 mm
Sand gravel, d ~ 4 mm

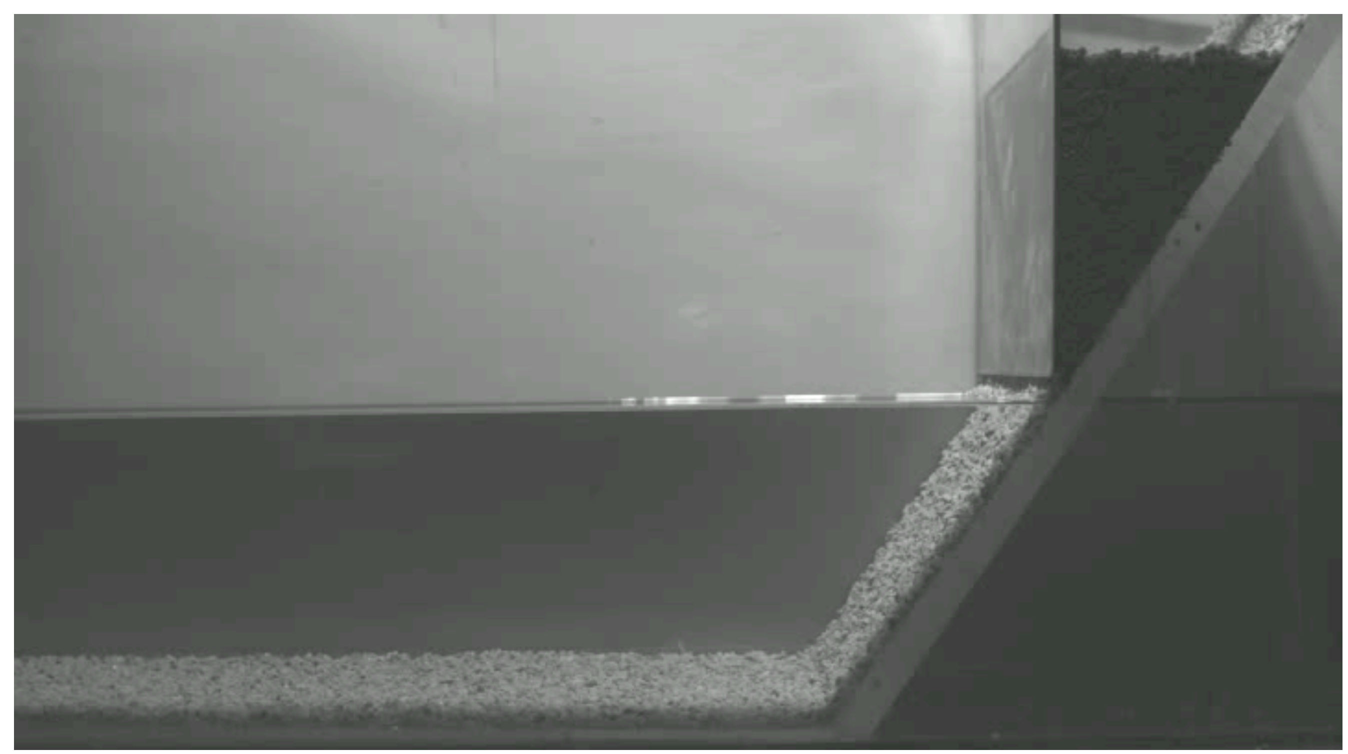
Viroulet *et al.*, J. Of Vis. 2013

# Generation by slump

Dry collapse vs
impacting water



Sand gravel
2kg, 50°, H = 15 cm



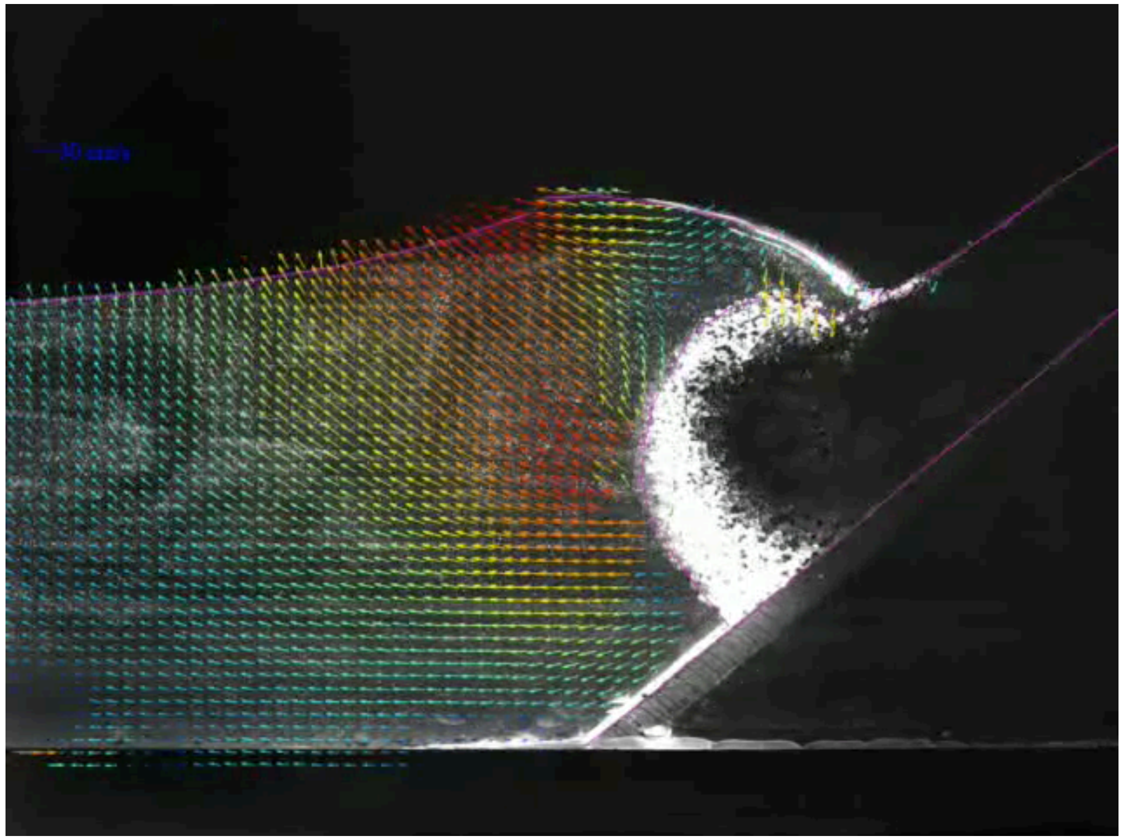
Viroulet *et al.*, Europhys. Lett., 2014

# Generation by slump

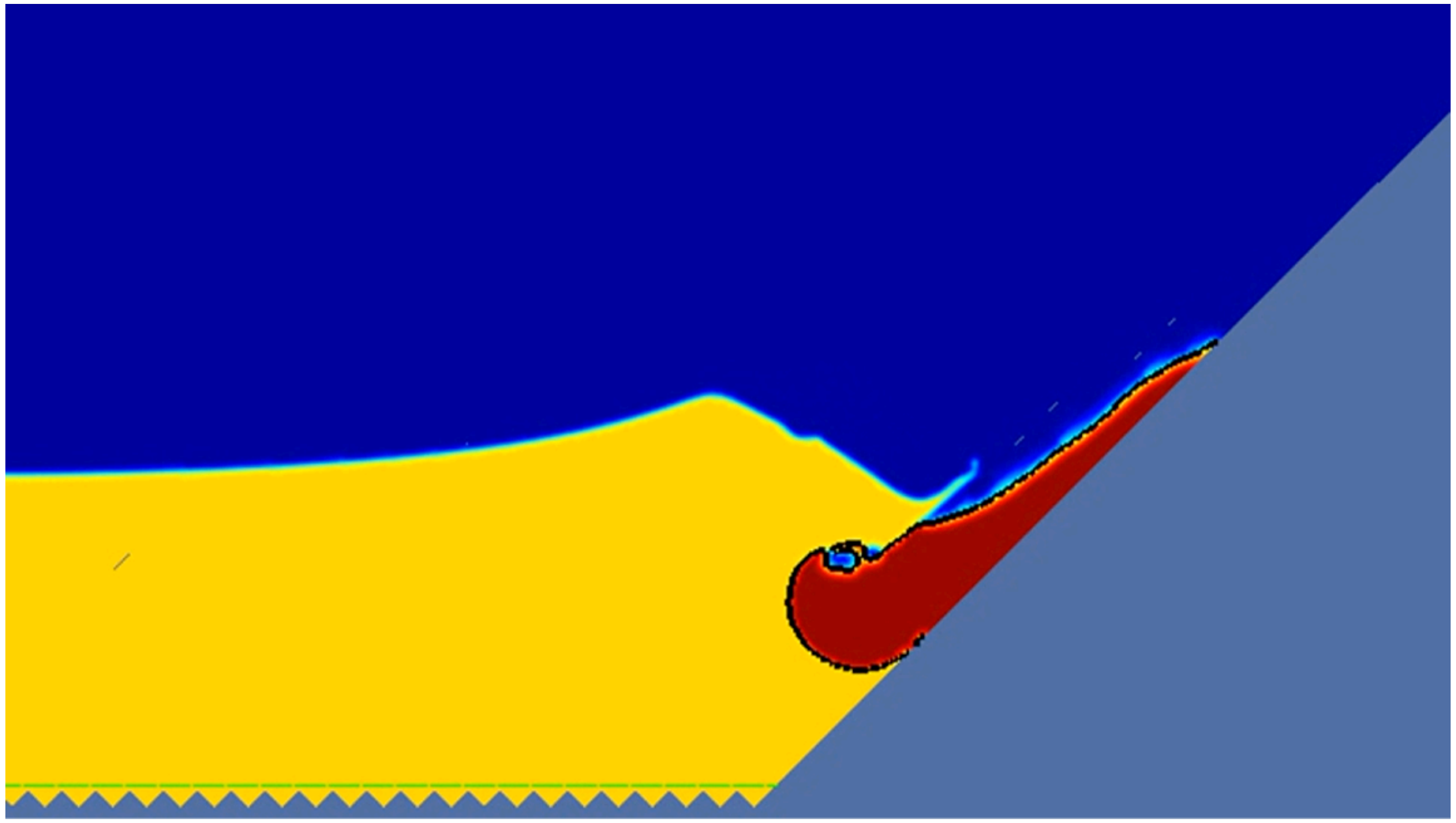
Rheology of granular flows :

- dry : Jop et al, *Nature*, 2006
- suspension/immersed : Boyer et al, *PRL*, 2011; Rondon *et al.*, Phys. Fluid, 2011
- from dry to wet : ??

Granular media approximated by a Newtonian or Bingham fluid (simulations performed with Gerris)



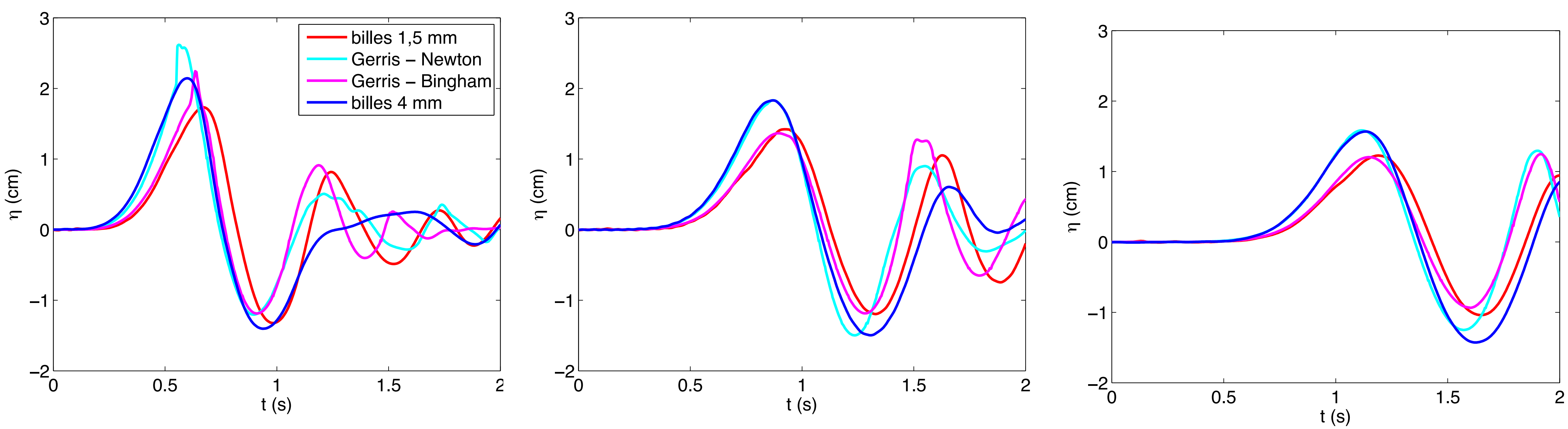
Glass beads, d=1,5 mm
θ = 45°, H = 15 cm



Newtonian fluid
θ = 45°, H = 15 cm

# Generation by slump

Elevation of the free-surface



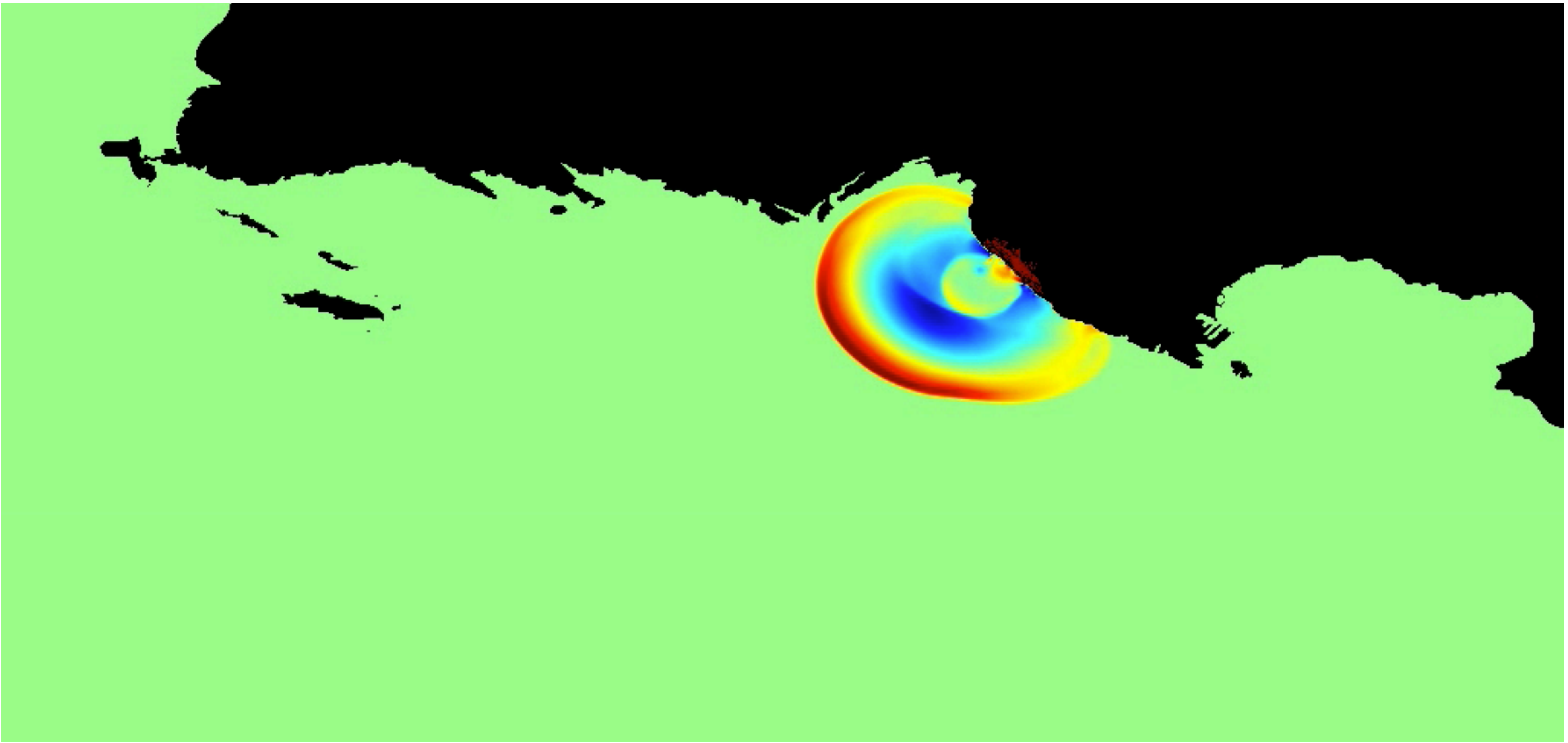

$\theta = 45°$

**Works perfectly using adjustable parameters ! ;-)**

# Generation by slump

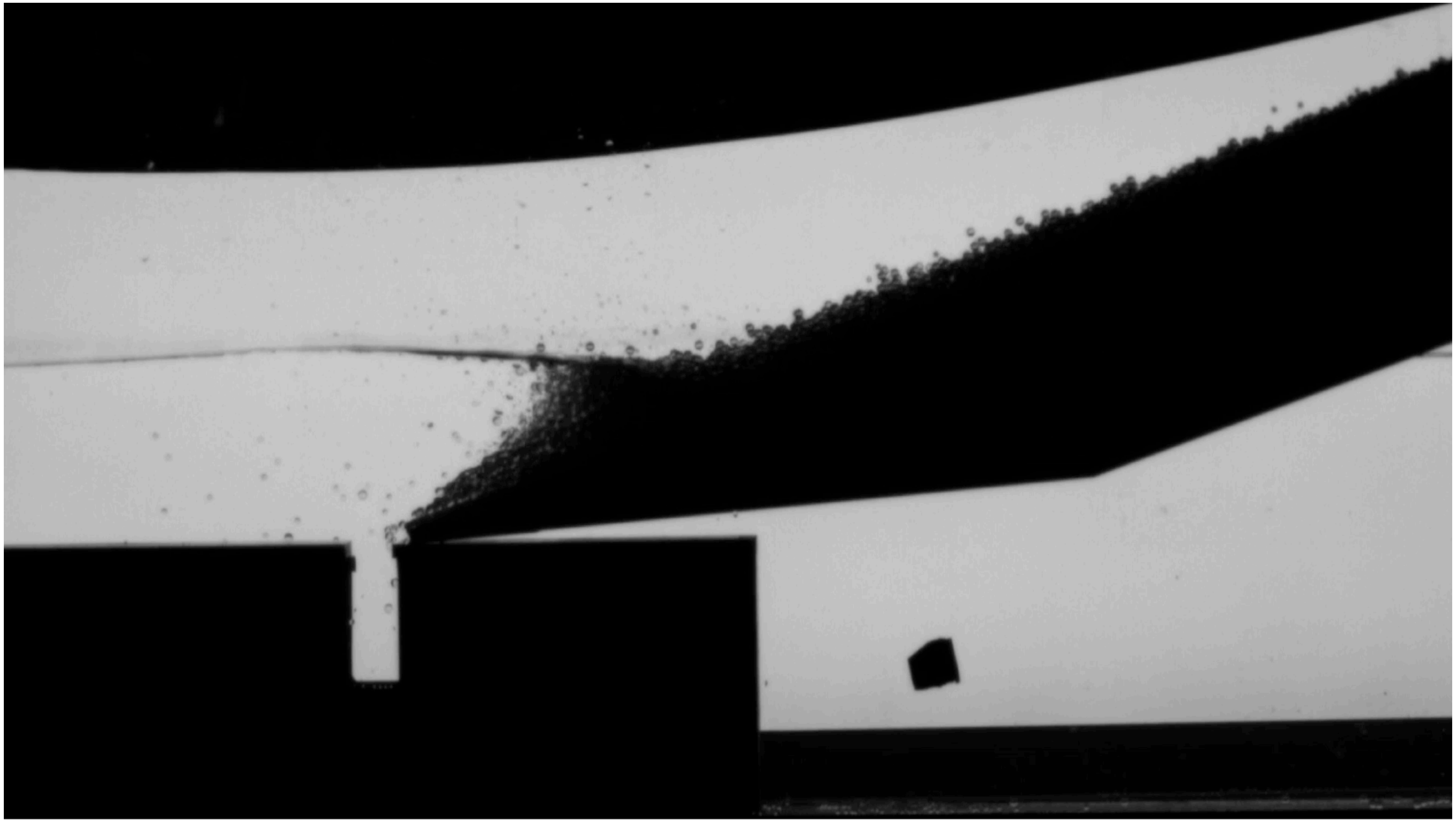
- removed part of the cliff using an ellipsoidal shape
- « filled » the gap with a fluid (water here)

- A two-layer model with a better rheology for the slide would be great !



## Steady uniform granular flow impacting water

Glass beads of 5 mm flowing on a rough base made of the same material (slope angle 20 degrees)



Very first results ! Experiment performed last Friday !

Free-surface, waves, complex rheology, surface tension, bubbles and drops

**perfect for Basilisk !!**

Thank you !