# Research grants for PhD students from the CSC

## Experimental assessment of the forces exerted by a tsunami-like flow on buildings and associated scour at the foundation of the building

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### 1. *Context : Risk mitigation in case of Tsunami / torrential floods and connected engineering problems*

The context of this project is the flood mitigation in case of Tsunami events or torrential floods. The objective is to characterize: (1) the force exerted by the inland flooding flows on obstacles such as houses, buildings and cars and (2) the scour produced at the base of the obstacle. The magnitude of such force/scour will determine if buildings will be damaged, destroyed or conversely, if they can be considered as shelters during Tsunami events. For smaller objects, like cars, streets furniture, trees, *etc.* they can likely to be taken away by the flows and hence form dangerous debris.

Tsunami events are one the most severe natural hazard. When these tsunamis occur in inhabited zones, the corresponding natural risk is one of the highest that can be encountered. It can additionally cause industrial risk as tsunami events are powerful enough to damage big plants such as nuclear plants. The project deals therefore with tsunami / torrential floods risks mitigation but also with possible related industrial risks.

As a tsunami reached the coast it invades the land and this inland-flow is a flooding flow with a depth of the order of one meter, with a front velocity of the order of 1 to 10 m/s, decreasing from the coast to the inner land. A torrential flood is usually generated by heavy rains (such as Typhoons) and flows down steep hills so that the velocity of the flow increases rapidly and it reaches a supercritical regime. When such supercritical inland flow reaches a building or a group of buildings, its kinetic energy is suddenly transferred into potential energy with three effects. First, the gain of potential energy corresponds to an increase of water height with possibly an overtopping of rescue zone on the roof of the building, or possibly water reaching buildings opening. Second, the gain of potential energy corresponds to an increase of pressure on the building face exposed to the flow, which experiences huge forces that can damage, destroy or knock it over, as it unfortunately occurred for instance during the Tohoku region Tsunami in 2011. Third, the complex flow pattern taking place at the base of the buildings can generate a severe scour and damage the building foundations, with an additional risk for the building stability.

### 2. *Scientific issues*

The inland flow is often supercritical as stated by observed characteristic Froude numbers higher than 1 (*e.g.* Nandasena *et al.*, 2012 ; Matsutomi *et al.,* 2001). This means that the flow velocity is higher than the speed of gravity waves at the surface of the flow. As for supersonic flows in aerodynamics (with quite different velocities), this causes the flow to act in a specific manner on emerged obstacles as buildings. Investigations at LMFA (Riviere et al., 2017) showed that the flow can skirt such obstacles following two ways (figure 1): a detached hydraulic jump or a vertical wall-jet (the so-called wall-jet-like bow-wave). These two flow forms lead to quite different velocity direction and water height on the obstacle face which are expected to correspond to very different forces on the obstacle face &

scour at its foundations. The condition of appearance of one flow form or the other was assessed for rectangular obstacles with a face perpendicular to the flow. The results are expected to be significantly modified with other orientations of the building, which should favor the flow deflection.

As detailed by Nistor *et al.* (2009), two phases of load on buildings can be considered: the wave impact, *i.e.* a high, fast (order of 1 s) load at the wave arrival on the building façade and the post-impact *i.e.* a smaller, constant (order of a minute) load when the inflow completely embeds the building. The wave impact against structures was studied by numerous researchers, *e.g.* Cross (1967), Asakura *et al.* (2000), Nouri *et al.* (2010). It is still an active topic, investigated both experimentally (*e.g.* Wüthrich *et al.,* 2016) and numerically (*e.g.* Carratelli *et al.*, 2016 who use both SPH and VOF methods). Special aspects such as overtopping (Chen *et al.*, 2015), resilience of a given construction technique (van de Lindt *et al.,* 2009) or damages caused by tsunami-driven debris (Ko *et al.,* 2014) are also investigated. The present project focuses rather on the post-impact forces that acts during several tens of seconds to tear buildings and vehicles off and to bring them away within the flow: the problem is thus that of an obstacle embedded in a locally steady flow. This problem has been addressed considering arrays of emergent obstacles, in the framework of aquatic vegetation (*e.g.* Tanino and Nepf 2008) and in the case of large obstacles (Herbich and Shulits 1964, Dupuis *et al.* 2016), showing significant variations of the force exerted by the flow depending on the packing conditions. In a recent work, Cassan *et al.* (2014) investigated the effect of the Froude number on the hydraulic resistance of emergent obstacles. They showed important variations of the drag on the obstacles as the Froude number increased. However, only few studies focused on the flow forces on an obstacle in a supercritical flow, leaving many open questions for the present project.

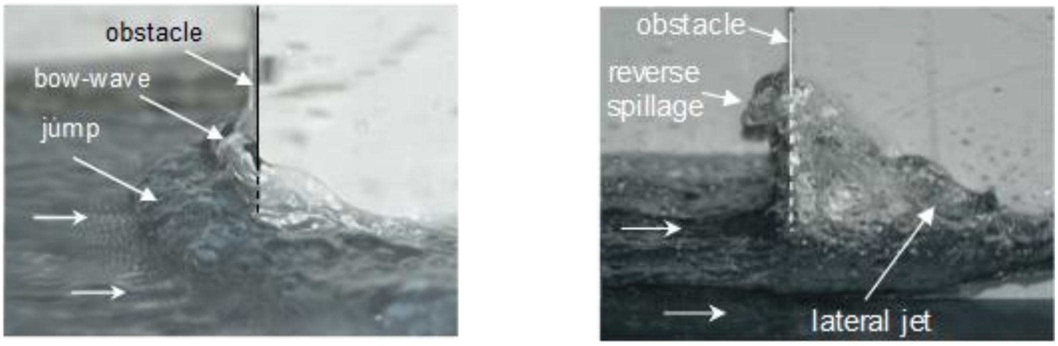


*Figure 1: Photographs of the supercritical flow around an obstacle : detached hydraulic jump (left) and wall-jet (right) – from Rivière et al., 2017.*

The topics of scour caused by a supercritical flow at the base of a building was recently reviewed by authors involved in this project along with collaborators (Link et al., 2019). To the best of our knowledge, the only work dedicated to this topic was performed by Mignot et al. (2016) in the detached hydraulic jump regime and revealed that while the flow pattern of supercritical flow skirting a mounted obstacle strongly differs from the more-classical subcritical case, the resulting scour does not dramatically changes from these well-studied subcritical scour patterns.

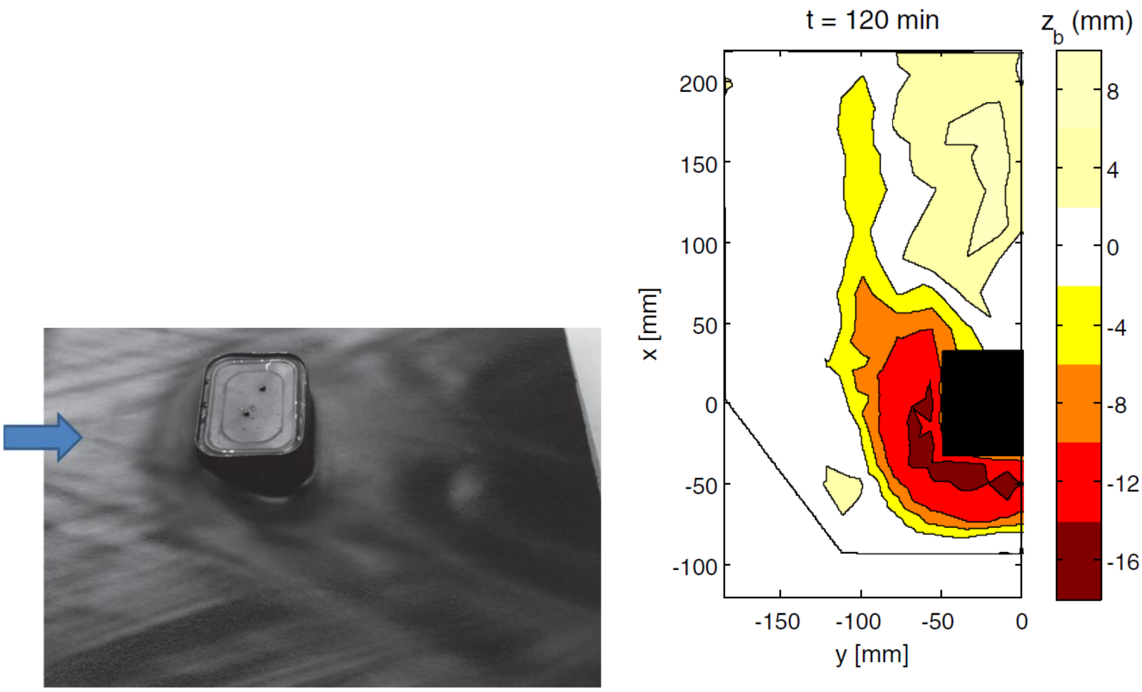


*Figure 2: Scour at the base of mounted obstacles in supercritical open-channel flows, from Mignot et al. (2016): photograph of the flow pattern (left) and final sour (red-orange) and deposition (light yellow) around the obstacle (right)*

### 3. Objectives and approach

The project aims at establishing the correspondence between the flow characteristics (depth and velocity), the size + orientation of the buildings and the hydrodynamics force that the flow exerts on the obstacle + the scour depth at the base of the obstacle. We mainly aim at:

- 1/ Estimate the forces and water depth on buildings (*i.e.* a flow of known or estimated depth and velocity) as a function of the flow and building characteristics.
- 2/ Assess if an orientation should be preconized for future buildings urban planning in regions at risk.
- 3/ Evaluate the dimensions / depth of scour at the base of the obstacle.
- 4/ Measure the force acting on the building once the scour at the base of the obstacle is established. This will permit to assess if the risk of building damage strongly increases due to the scour.

These objectives will be reached using laboratory experiments, adopting the right scale rules. The PhD will benefit from large installations available at LMFA and particularly:

- A large scale flume of with 1.2m where preliminary measurements were performed: see the video in English at : https://www.dailymotion.com/video/x6hcjov
- A transparent tilting flume where high slopes can be reached to produce very rapid flows in controlled conditions
- A hydrodynamic balance dedicated to measure the hydrodynamics forces exerted by open-channel flows on mounted obstacles.

- A system of fringe projection profilometry adapted from Cobelli et al. (2009) and Aubourg and Mordant (2016)

*Figure 3: Photographs of the available large scale flume (left) and transparent tilting flume (right)*

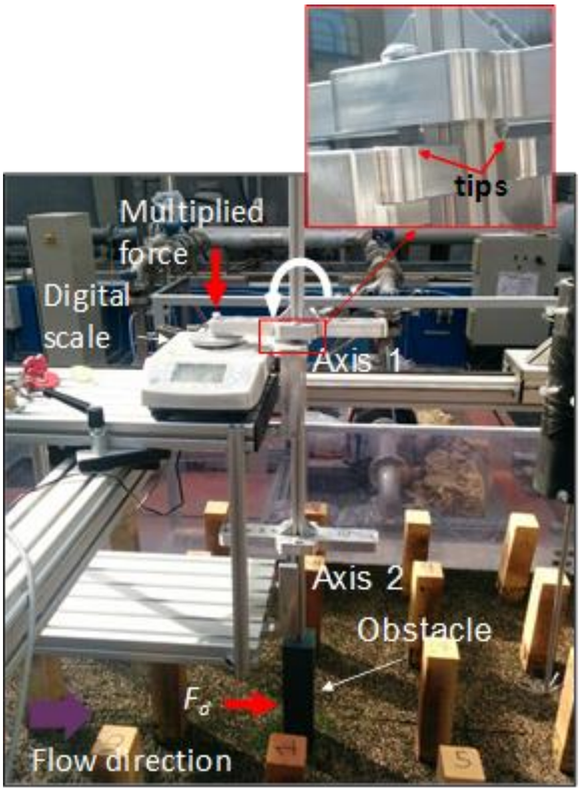


*Figure 4: Photograph of the hydrodynamic balance (from Guillén-Ludeña et al., 2020).*

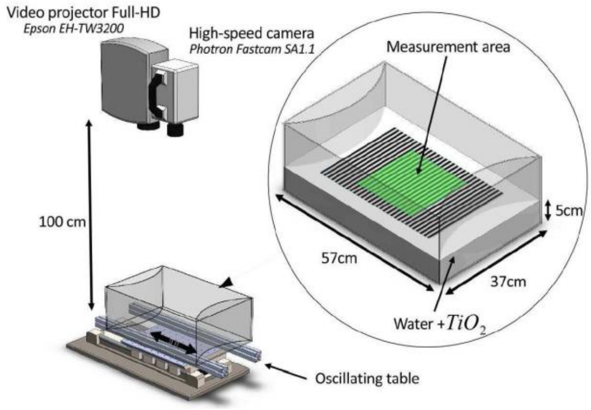


*Figure 5:* Sketch of profilometry by fringe projection, from Aubourg and Mordant (2016)

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