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PUMP Erosion Test : an erodimeter for field studies

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ABSTRACT

Water erosion is a natural phenomenon that can have a strong influence on the stability of civil engineering structures. Our objective is to propose a low cost field equipment allowing to generate and characterize the erosion of sediments present under a few decimeters of water. The PumpET (Pump Erosion Test) aims to be a field device dedicated to the measurement of erodibility, defined as the capacity of a material to erode river sediments in place. Its basic principle is the suction of water downstream of a centimetric submerged test channel placed on a sediment bed. The suction generates a controlled almost unidirectional flow inside the channel in order to erode the sediment. The erosive phenomenon is triggered when the critical constraint for the movement of the grains in the test zone is reached. For this purpose, the spatial and temporal evolution of the deformation (in mm) of the sediment surface enclosed in the measurement section will be followed. In this paper we do a brief state of the art before presenting the technical choices made. Then we present some results and discus them.

INTRODUCTION

Civil engineering structures above rivers are impacted by various natural phenomenons that can affect their stability. Erosion and scour are among the most impacting and it proves important to quantify the erosion processes in their vicinity. The objective of the present study is to propose a "low cost" field equipment allowing to generate and characterize the erosion of sediments present under some decimeters of water. By "sediments", we mean the materials that make up or are deposited on the bottom of a river, a harbor or a canal and that are made up of organic or mineral elements, cohesive or not. By "field device", we mean light, autonomous equipment that is easy to transport by hand along a river or foreshore, and under the name "low cost": inexpensive, easy to manufacture and repair.

The PumpET (Pump Erosion Test) aims thus to be a field device dedicated to the measurement of erodibility. Its founding principle is the suction of water downstream of a submerged test channel placed on a sedimentary bed. The suction generates a controlled unidirectional flow inside the channel in order to erode the sediment. The erosive phenomenon is triggered when the critical constraint for the movement of the grains in the test zone is reached. During the erodibility test, the pumping water could be recovered for laboratory analysis of the granularity and organic fraction of the eroded sediments.

After a review of some of the many existing erodimeters, we will present the main steps in the development of the PumpET prototype, the difficulties overcome, and the results of the first experimental campaigns.

STATE OF THE ART AND REVIEW OF EXISTING DEVICES

Erosion is commonly understood as the movement of solid particles under the shear stress that flow exerts on the sediment-water interface. A minimum shear stress, also known as the critical shear stress τc, is required to erode the sediment.

Since Du Boys (1879), who proposed a law based on bed slope and water height, many authors have proposed laws of which Jerez et al. (2011) showed a graphical comparison. Other colleagues, like Dey et al (2008 and 2019), presented a review oriented on erosion threshold. These works show the difficulty in predicting the resistance of a given sediment to an erosive phenomenon, which is hardly surprising if one refers to the range of physical and chemical properties involved (Grabowski et al., 2011).

Approaching the question of erosion quantification or erosion threshold from another angle, many colleagues have proposed devices for either laboratory or field work (Jerez et al, 2011) and Regazzoni (2009) showed that the shear stress threshold is strongly dependent on the device used. More recently, Perez et al (2010) proposed a field device using a propeller but whose spatial impact is poorly documented, while Grant et al (2013) proposed a so-called field device but requiring prior sampling, which may alter the characteristics of the sediment. In the same time than our work, N'doye et al (2016) proposed a device using a wheel to generate the erosion and He et al. (2021) proposed a device using an erosion chamber that is placed on the sediment,

PROTOTYPE DEVELOPMENT

A review of previous projects shows that the experimental field devices were not very or not at all transportable and of significant size. Going back to the basics, the goal is to have an easily portable, autonomous and light device. For this we reduced the observation chamber to a small section vein, in order to reduce the power of the pump necessary to reach the targeted speeds, but also the size of the power battery of this pump. Finally, we took the option of a low cost material by using components easily found in the market, for example we use standard PVC piping of 40 mm diameter connecting to a vein of Altuglass section.

The PumpET is a compact device (Figure 1), weighing less than 3 kg and costing less than 1000 euros (excluding labor). It should be noted that some initial hints have been implemented to improve the measurement:

- the measurement chamber is of variable cross-section. The inlet (80 x 30 mm) is twice the cross section of the outlet. The evolution of the average velocity is practically increasing linearly along the chamber, the idea being that the triggering should appear downstream where the velocity is the most important, the position of the erosion threshold along the chamber would allow to determine a precise triggering velocity;
- a sportcam films the chamber during the pumping phases, this allows to determine the movement of the sediments;
- two laser planes inclined by 45° are projected through the transparent upper wall of the measuring chamber. The deformation of these planes should allow the measurement of the hollowing of the chamber;
- the immersed pump is centrifugal (figure 1), it allows to ensure an average speed of 0.7 m/s at the maximum power in 12V (it is an 1100 GPH). It is controlled in power steps (PWM) with a micro-controller;

From an erosion determination point of view, the pump generates a current in the measuring chamber. This chamber is filmed in order to determine if, for a given flow rate, the grains trapped in the chamber are set in motion or not.

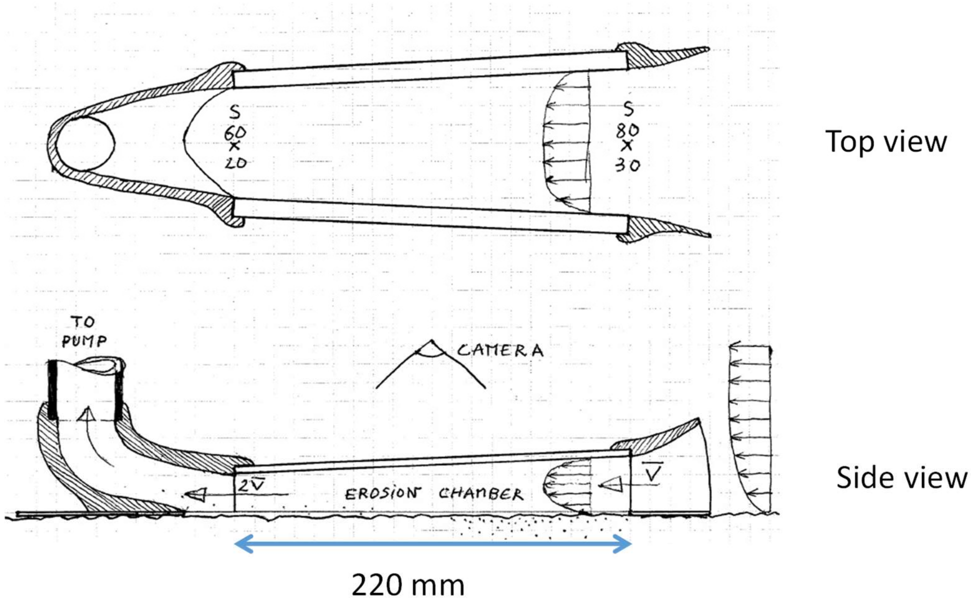


Figure 1. General view of the prototype.

RESULTS

The power of the pump is controlled by PWM: Pulse Width Modulation. This digital parameter varies from 1 to 256. The calibration was done in the laboratory in a still water tank. We varied the power of the pump and measured the volume delivered during 10 seconds for each power level. Knowing the section of the chamber, we can deduce the speed (figure 2) of the flow at the narrowest point (downstream of the chamber).

A test campaign was carried out in August 2022. It confirmed that the device is compact and easy to carry. A person on foot can use the PumpET without difficulty until he has water at his waist. The device can be used for flow speeds up to 1 m/s. Beyond that, it is difficult for the experimenter to simultaneously ensure his safety and to hold the measuring chamber at the bottom. Reflection is in progress to improve this.

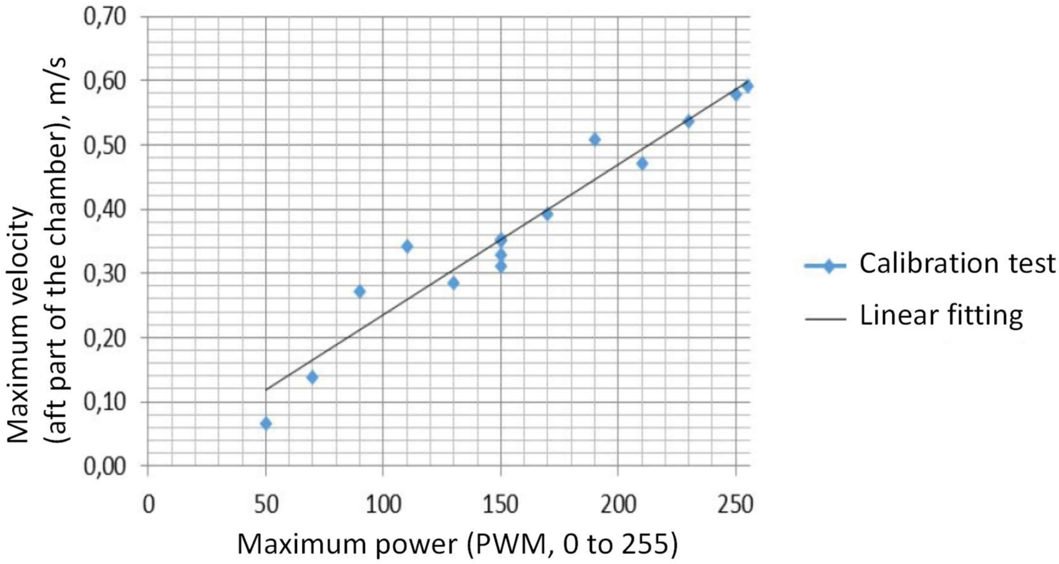


Figure 2. Pump calibration curve.

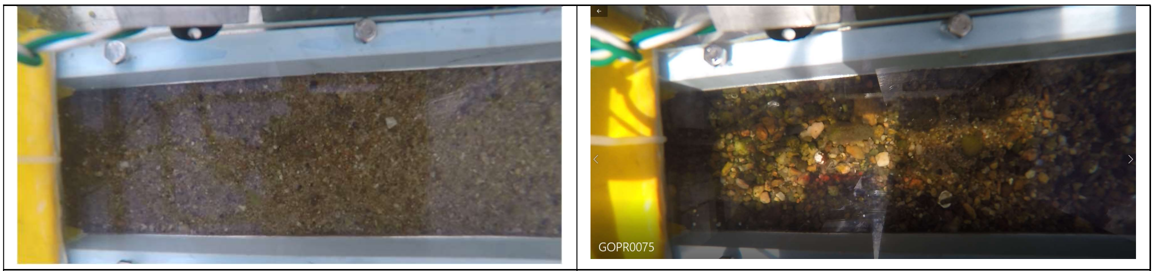
In addition, it should be noted that the tests are destructive in the strict sense since the sediment under the chamber may have been eroded. However, as the footprint is limited, it is possible to take sediment from outside the chamber for later analysis in the laboratory (grain size distribution but also organic fraction).

As recalled by Paphitis et al. (2005), the determination of the velocity threshold for erosion has given rise to numerous works from which it emerges that here again the threshold depends greatly on the way of determining it but also on the erosive phenomena undergone by the sediments. Another family of approaches can be represented by Chegini and Tait (2011) which proposes the automatic determination of the movement of grains using images filmed above the free surface. Our method is similar in spirit but still with a deliberate choice of very controlled cost, lightness and field equipment.

For the feasibility level, we used a step-by-step method. The scene filmed by the camera was divided into 8 zones in which we quantified the number of moving grains (white if all are motionless, yellow if one grain is moving, orange if a few grains are moving, red if the movement is generalized).

Figure 3 shows two examples of the images that are recorded during the measurements with the GoPro camera. Figure 3a corresponds to measurements in the

Loire river in Saint-Clément-des-Levées with a flow velocity estimated at 0.5 m/s and Figure 3b to measurements in the Loiret river in Saint-Hilaire-Saint-Mesmin with a flow velocity estimated at 0.2 m/s.



a) Saint-Clément-des-Levées | b) Saint-Hilaire-Saint-Mesmin

Figure 3. View of the sediments below the erosive chamber.

After the measurements, at the place where the measurement chamber was, we have sampled the sediment manually with a tube (about in the middle of the chamber). It can be seen that Saint-Clément-des-Levées sediment is finer, that is corroborated by the grain size distribution (Figure 4). It should be noted that a significant amount of vegetation is present in Saint-Hilaire-Saint-Mesmin and therefore many particles in suspension circulate between the camera and the measurement chamber. It is a point which will be treated for an automation of the treatments.

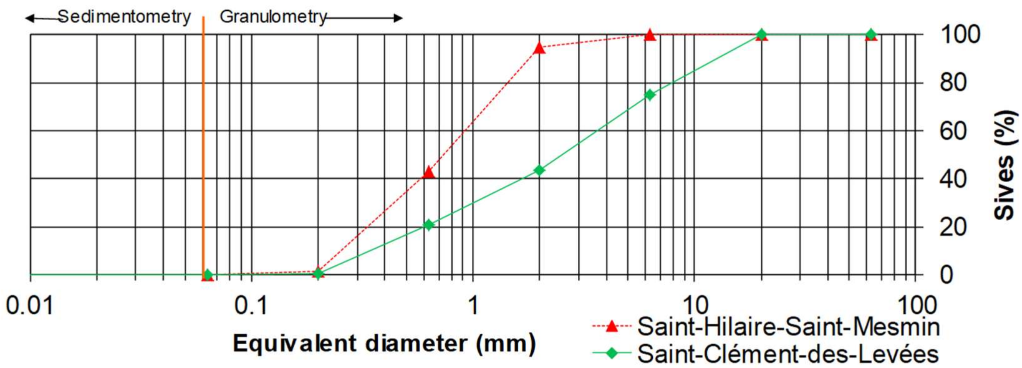


Figure 4. Grain size distribution of the 2 sites.

Using the videos, it is possible to quantify the movement of the grains. Nowadays we do not have any automatic system so the results are “by expert opinion”. Due to the shape of the measurement chamber, the velocity increases from the inlet (fore) to the outlet (aft) part of it. And various discharge values are applied. So the mean velocity can be incremented into the chamber. Figure 5 shows that the finer sediments of Saint-

Clément-des-Levées are quickly eroded with a uniform behavior in all the chamber. In Saint-Hilaire-Saint-Mesmin, the sediment is coarser and the erosion process starts for a faster velocity. Moreover, a great spatial variation can be seen. This is related to the biggest elements that can be seen on Figure 3.

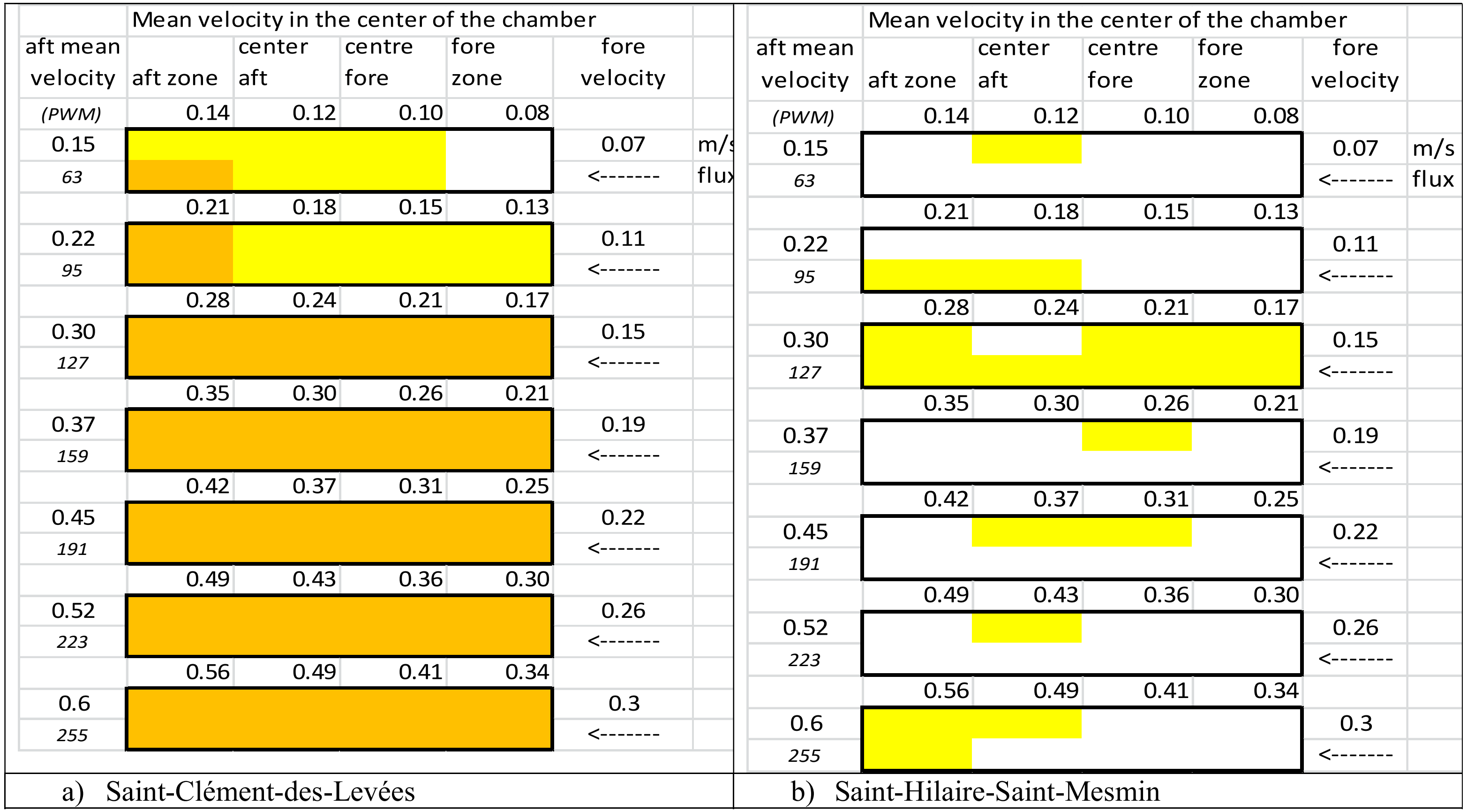


Figure 5. Movement of grains as a function of mean velocity in the chamber (white: no movement, yellow: one grain moves, orange: various grains move, red: generalized movement.

CONCLUSION

A prototype erodimeter, called PumpET, was designed and built with the deliberate intention of creating a lightweight, low-cost device that could be easily implemented by a small team. In this, the first step of the project has been achieved. The tests carried out in the field have also validated the concept since it is possible to observe the movement of the particles in the bed located in the lower part of the measuring chamber.

Various improvement projects are already under consideration, such as the installation of a sensor, like a sailboat log, visible in the field of the camera and allowing to determine the speed of the flow near the measuring chamber or the adaptation of a battery transport system allowing to work with higher water heights, the implementation from a machine allowing to reach heights higher than 1 m of water.

For this purpose, the spatial and temporal evolution of the deformation (in mm) of the sediment surface enclosed in the measurement section will be followed. Turbidimetric measurements could be considered, but their implementation requires taking into account the mass and bulk of the sensors.

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