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Highly efficient innovative shallow-water based Sea Water Air Conditioning solution for the Channel Area

EUROSWAC

WP T2.3
Self-Burying System for SWAC pipes Tests Report

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1. Introduction

1.1. EUROSWAC Project Description

EUROSWAC Project is a highly efficient innovative shallow-water based Sea Water Air Conditioning (SWAC) solution for the Channel Area. It aims at designing and validating an innovative, cost-efficient, and environmentally friendly solution for cooling production, using English Channel's seawater as a refrigerant, thanks to the difference between the cold ocean water temperature and the ambient air temperature.

While the need for cooling in large coastal cities is increasing at UK-FR levels (due to climate change), cooling is still mainly produced through chillers, a technology using large amounts of electricity generated partially by fossil fuels, slowing down the ability to meet Channel Area (CA) energy-climate objectives. EUROSWAC Project intends to demonstrate the ability of using the Channel seawater for free cooling, adapting an existing technology used in tropical areas, to the low water depth and temperate of CA.

Based on the complementary expertise of 11 UK-FR partners from the academic and industrial fields and on the analysis of Channel's unique features, EUROSWAC Project aims to develop and test a SWAC prototype at the Brixham laboratory and National Lobster Hatchery in UK. This shallow-water based SWAC system will be the first to support an enhancing aquaculture food-stock, which will represent major benefits regarding CO2 emissions, lifespan, and costs compared to existing solutions.

The EUROSWAC Project will include two R&D parts:

- A Self-Burying Rigid Pipeline System for shallow water and landfall section (where it is necessary to bury the pipeline)
- A flexible pipeline system for the offshore section (where burying of the pipeline is no more required)

These objective of the EUROSWAC Project is to minimize of the CAPEX of the SWAC system by reducing both material and the installation costs.

1.2. Context of T2.3 –Self-Burying Rigid Pipe System

DORIS Engineering and DeProfundis are in charge to develop a Sea Water Air Conditioning (SWAC) system. In this frame, several studies have previously been performed highlighting the significant cost of the marine works, required to install the SWAC pipeline on the seabed, with direct impact of the Capital Expenditure (CAPEX) of the system. One promising solution consists in using a self-burying rigid pipe system in order to avoid the mobilization of dedicated marine means for the installation of the pipeline below the seabed, and thus significantly reduce the cost of the marine works.

The Self-Burying System (SBS) is composed by 3 main subsystems:

- High pressure water injection subsystem to be used for fluidifying the sand below the rigid pipe in order to be able to suck up the sand.
- Air injection subsystem to be used to create turbulences below the rigid pipe in order to improve the water injection system.
- Suction subsystem to be used to suck up the sandy water below the rigid pipe.

The aim of this SBS is to bury a Rigid Pipe to be used for transporting the cold sea water from offshore to onshore for cooling production.

It is worth highlighting that this SBS concept has already been tested with a small-scale prototype in an aquarium but has never been tested with a large-scale prototype.

The objective of DORIS Engineering and DeProfundis is then to design and built a larger-scale prototype (18m length) and to test it in a trench under conditions as close as possible to seabed, in order to confirm the promising results observed with the aquarium small-scale prototype.

The main purpose of this R&D study is to demonstrate that the Self-Burying System (SBS), described here above, will be able to carry out the burying of the SWAC rigid pipe.

1.3. Purpose of this document

The purpose of this document is to present the specifications and the design of the SWAC Pipe along with its SBS and describe the tests performed so far for demonstrating the feasibility of burying a SWAC rigid pipe under a sandy seabed by only using the SBS as defined here above.

This document represents the deliverable requested from DORIS Engineering and DeProfundis work in Task 2.3 of the EUROSWAC project.

The document includes the following Sections:

- Background and objectives
- Summary and Conclusions
- Test specifications
- Prototype description
- Prototype assembly and initial design
- Description of the tests and iterations on the prototype

2. Summary & Conclusions

2.1. Prototype Description & Objectives of the Tests

The prototype is composed of:

- A rigid Pipe of 110mm diameter and 18m length
- The Self-Burying System (SBS) equipped with a Water/Air injection subsystem (blue tubes) and suction subsystem (grey tube), along with their dedicated pumps and valves

This prototype has been tested in a 20m length trench, filled with sand and water in order to be as close as possible to seabed real life conditions.

The objective of the tests is to demonstrate that the Self-Burying (SBS) is able to carry out the burying of the 110mm SWAC rigid pipe below the sand.

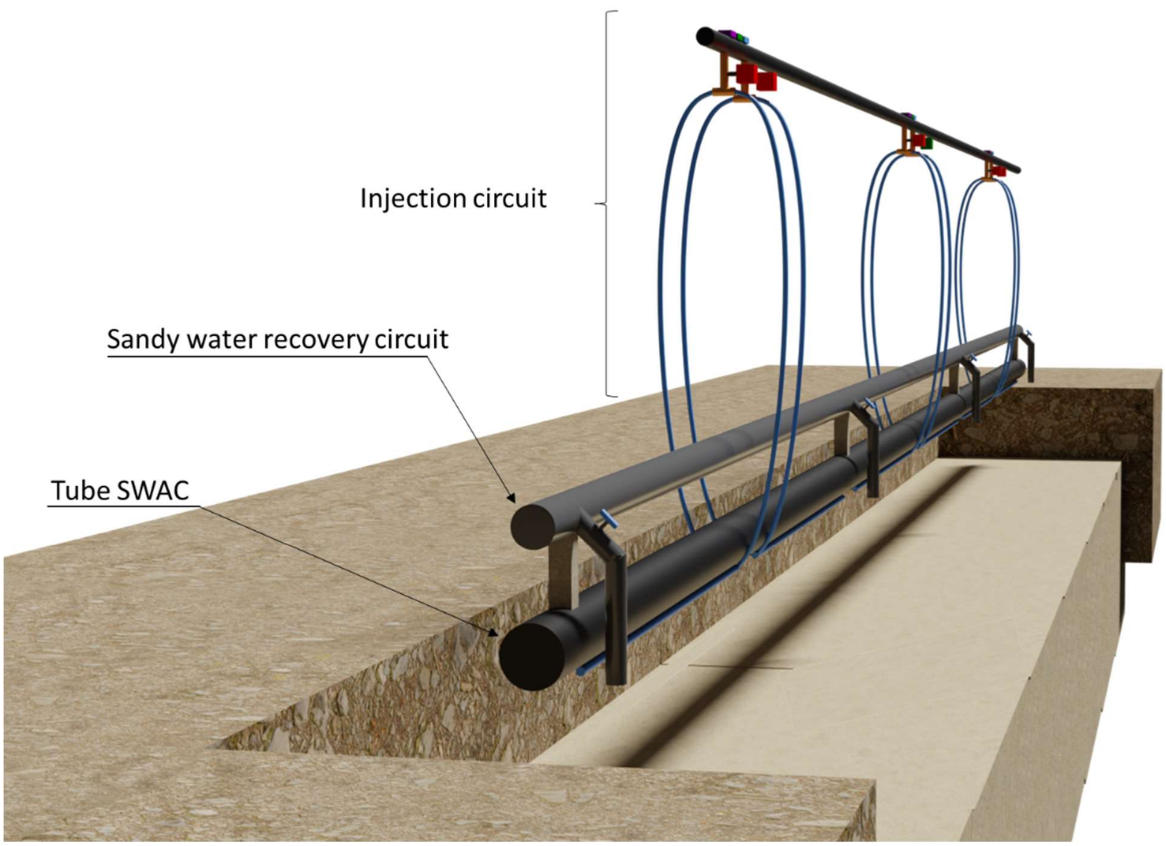


Figure 1 : Diagram of the prototype

The following picture Presents an overall view of the site where the prototype has been tested. For the tests purpose, a trench of 1m depth and 0.80m width was dug at the vicinity of a small river for pumping water into it. This trench was filled with sand up to 60cm depth and the prototype laid on it.

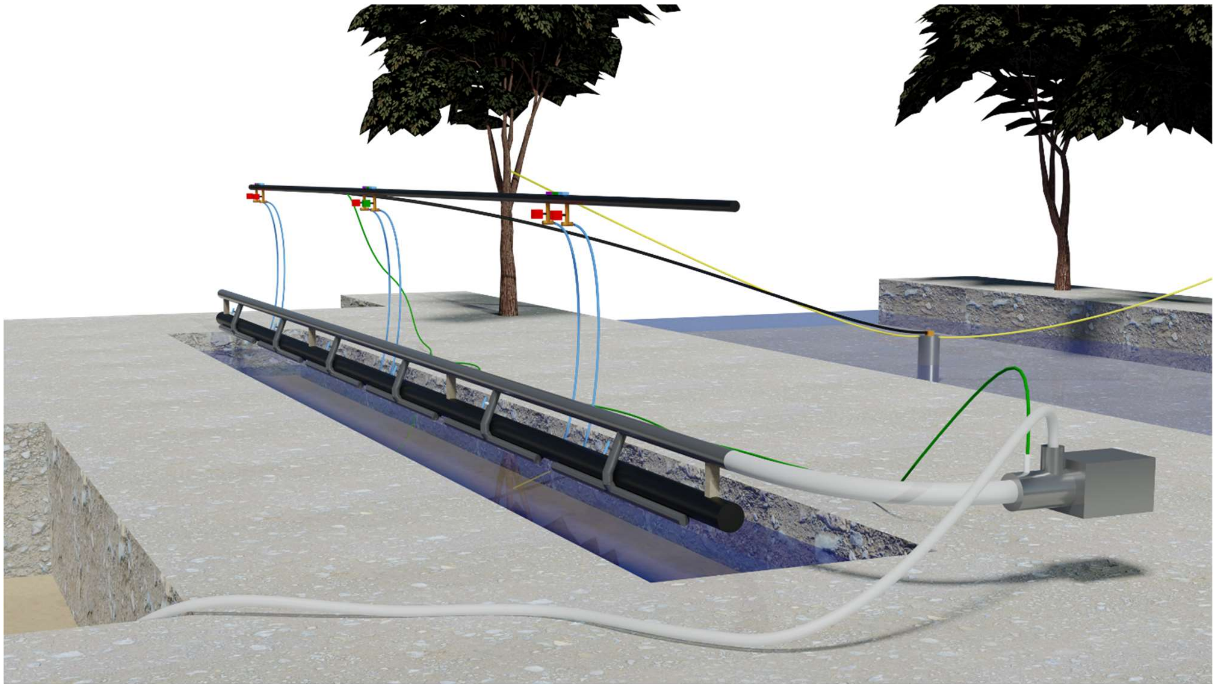


Figure 2 : Simplified view of the test site

2.2. Tests and Results

The prototype was assembled during the summer 2022 , tested in autumn 2022 and a final test was performed in March 2023.

Several tests were performed, in order to assess the assumptions and improve the SBS.

The main outcomes of the tests in Autumn 2022 are:

- The rigid pipe sank into the trench sand of about one diameter (110mm) over a length of 3m.
- To achieve this performance, the specifications of the SBS are:
  - For the water jetting system:
    - Holes with an optimum diameter of 3mm
    - Holes located below the SWAC tube, always directed perpendicular to the sand
    - Holes must be with a minimum spacing to allow for a uniform jetting pressure 12 holes jetting per meter.
  - For the sand suction system:
    - Several small nozzles evenly distributed
    - Nozzles with a diameter of 20mm
    - Suction nozzles to be placed front of the water jetting holes
    - Suction valves located in the middle of the suction system

The tests performed in March 2023 confirmed that the prototype assembled, optimized and tested was suitable for drawing the following conclusions:

- The suction system was operational.
- The sand suction system was necessary but was also the weak point of the model because the suction pump was managed by “ear and eye”
- The sand is well liquefied by the injectors, broken up by the injection of compressed air, and then sucked out properly.
- The removal of the sand results in the sinking of the pipe.

2.3. Conclusion & Perspectives

The main conclusion we can draw from the tests performed so far is that the Self-Burying System (SBS) is able to carry out the burying of the 110mm SWAC rigid pipe. This is an outstanding performance which means that the SWAC pipe, in real life, may be installed below the seabed without the need of any marine means such as costly installation vessels usually used for such works. A preliminary cost estimate comparison has concluded that the SWAC installation cost can be divided by 10 with a Self-Burying System.

Nevertheless, despite of this promising conclusion, additional tests would need to be performed to optimize the prototype:

- Replace the rigid suction collector with a flexible corrugated one in order to increase flexibility of the system and thus ease burrying by sections (and reduce iterations)
- Install a window (= transparent pipe) in the sand apsiration circuit to judge the quantity of sand in the water
- Reduce pressure losses in aspiration circuit
- Test with only one pump in order to assess potential optimization

A test campaign is planned to be carried out during the summer 2023 for this purpose (out of Euroswac project scope), and will be carried out for this purpose.

Extrapolation to an offshore environment will require specific measures such as:

- adapted materials
- welded connections to avoid leaks
- improved way of operating valves for isolation of the working sections.

3. References

N°	Doc Number	Title
Ref. 1	HOLD – no number yet	Self-burying cost estimate - not issued yet

4. Definitions and Abbreviations

4.1. Definitions

NA

4.2. Abbreviations

The following abbreviations are used in this document:

CA	:	Channel Area
CAPEX	:	CAPital EXpenditures
HDPE	:	High Density Polyethylene
ID	:	Internal Diameter
SBS		Self-Burying System
SWAC	:	Sea Water Air Conditioning

5. Background and objectives

5.1. SWAC systems and reason for burying the pipelines

The SWAC principle is to pump cold deep water and to bring it back to shore to feed thermal exchangers through underwater pipelines that can be of several kilometers long. During its transportation, the pumped water is warmed up by a few degrees.
Arriving in shallow waters, these pipes are subject to multiple constraints:

- Thermal constraint: the hotter shallow water contributes to the heating of the pumped cold water
- Mechanical stress due to swells and currents
- Risks of damage due to human coastal activities such as fishing

Burying the pipe is mandatory to avoid all these constraints.

5.2. Existing solutions for burying the pipelines

Pipe-jetting is a usual means used to bury pipelines since 1970s. It consists in digging a trench with pressure jets. Traditionally, this method involves spraying water under pressure onto/into the sand. As shown here below, the pressurized water jet fluidizes the sand and transports it. This will create a lifting of the sand as well as a deposit. The jetting vessel goes back and forth and gradually dig the trench.

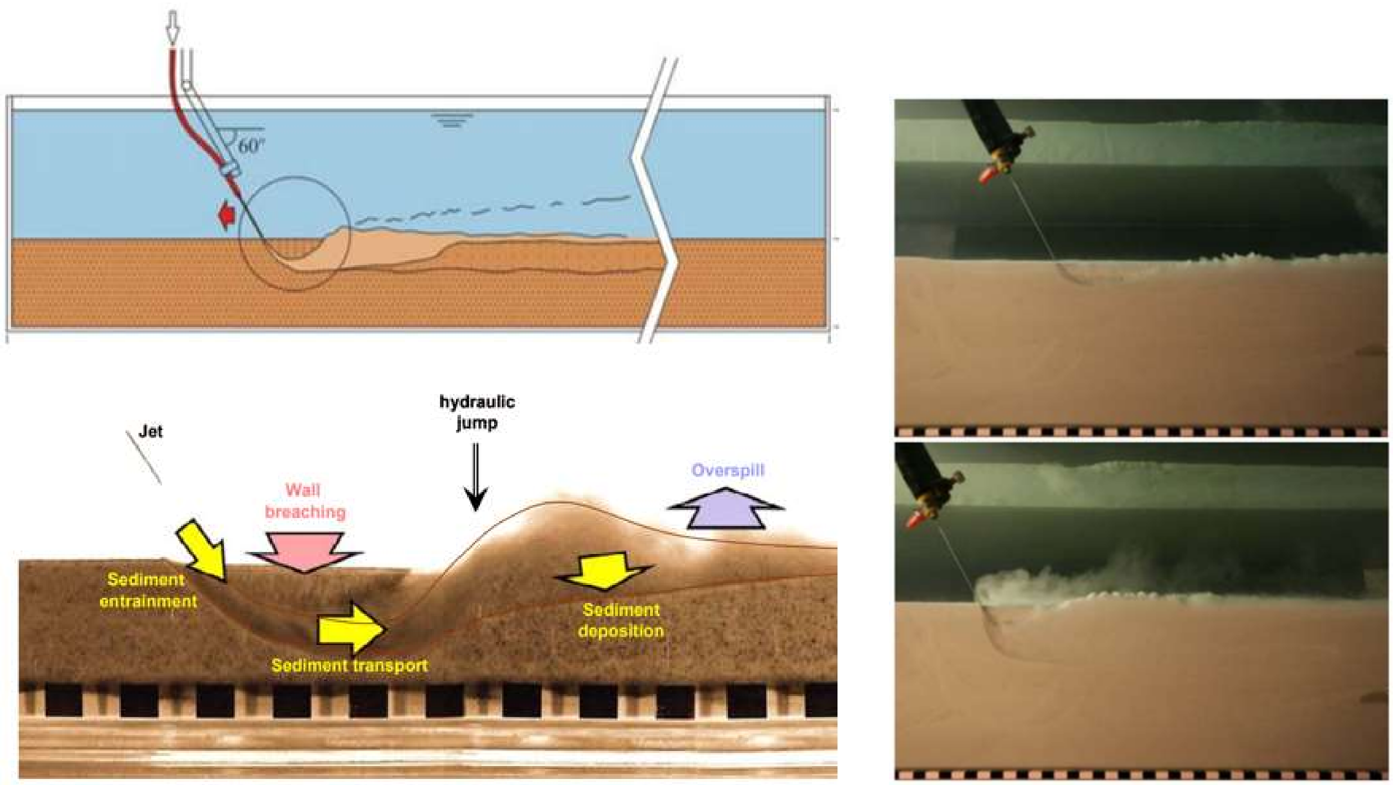


Figure 3 : Diagram of the behavior of sand fluidized by a pressurized water jet and tank tests

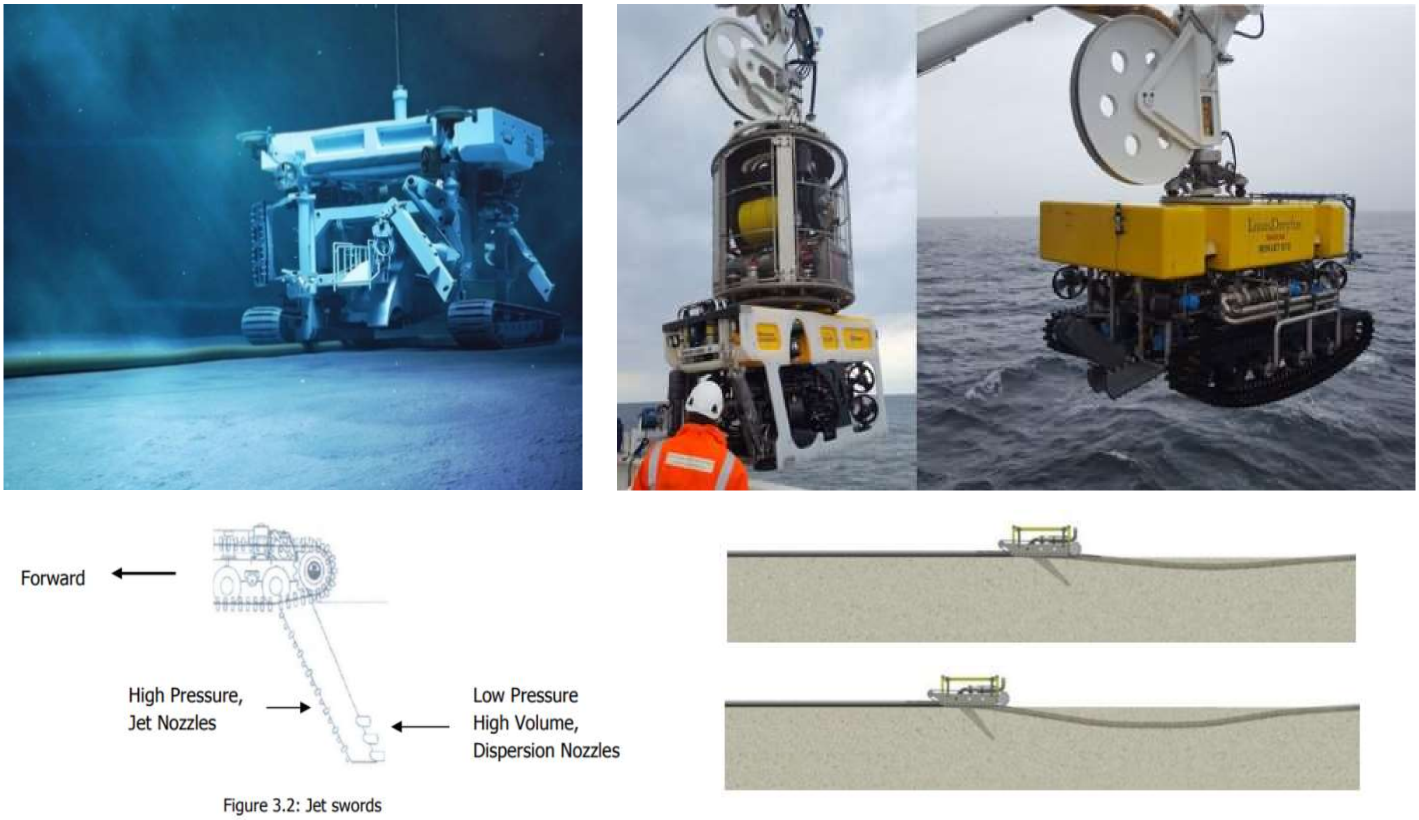


Figure 4 : photos of the ROV and explanatory diagrams of the burying principle

Dedicated underwater vessels were based on this process. These machines move underwater with the help of tracks and are always connected to the boat by cable. They fluidize the sand on which the pipe is placed. The pipe sinks into the fluidized sand and is buried.

This pipe burying method is very expensive because it requires the rental of the dedicated ROV(s), associated boat, and associated operators.

5.3. Presentation of the Self-Burying system

The self-burying system is attached to the SWAC tube and is composed of:

- Two pressurized water circuits placed directly under the pipe (The blue pipes on the sketch) to be encased along its entire length. These two circuits are tubes pierced with small holes at regular intervals which will be used to project water (and/or air) under pressure below the sand to dig a trench.

- The suction system (in yellow) pumps the sandy water generated by the water jets in the trench. The sandy water is evacuated to a tank dig in shallow water to prevent from disturbing biodiversity by lifting too much thin particles in the water.

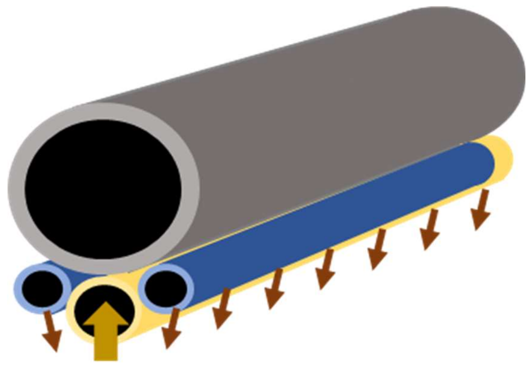


Figure 5 : Schematic diagram of the pressurized water injection under the SWAC tube (blue) and the sandy water suction (yellow)

This system aims to bury the SWAC tube by sections of 10 meters, thanks to the flexibility of the SWAC pipe.

A part of injection and suction systems will be buried with the pipe and therefore left in place after sinking while the other part will be recovered to be reused for other projects:

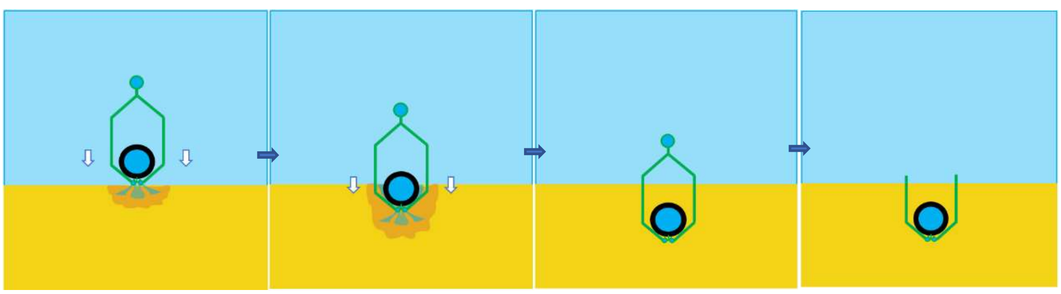


Figure 6 : Cross-section of the SWAC pipe in the sand

Based on a previous study, the cost of marine means represents nearly half of the SWAC CAPEX, and the use of a self-burying system could save a large part of the total CAPEX (see document dedicated to the cost estimate). This CAPEX reduction is linked to the use of a simple system driven from shore instead of a dedicated naval mean.

6. Test specifications

The goal of this project is to design, build and operate a reduced scale prototype that would demonstrate the efficiency of the self-burying system.

6.1. Background, previous tests

A first prototype at 1/27th scale (20mm diameter pipe) was realized and tested by DeProfundis in 2017 in a small aquarium. The result was conclusive, the pipe is embedded in the sand of the aquarium.

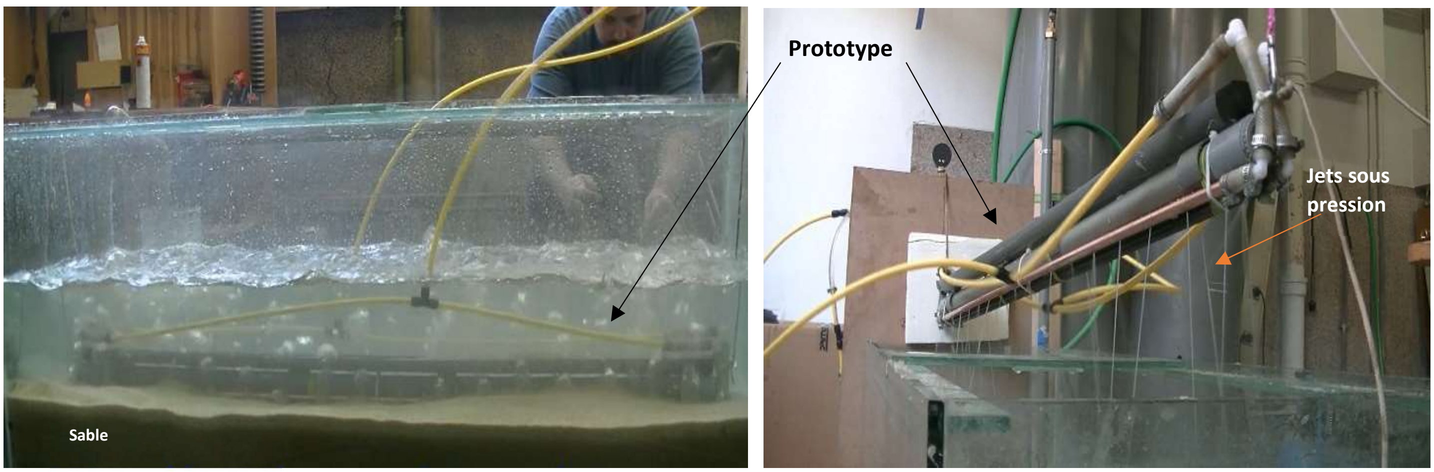


Figure 7 : Photos of the tests of the first prototype tested 5 years earlier

6.2. Prototype scale

The prototype used for EUROSWAC is on a 1/5 scale: 110 mm diameter SDR 11, 18 meters long and tested in a 20 meters long trench, 1 meter deep and 70 cm wide. The tube's diameter and SDR was chosen:

- to ensure the tube flexibility is enough for a silting per section.
- to fit the dimensions of the test site on which the trench will be dug

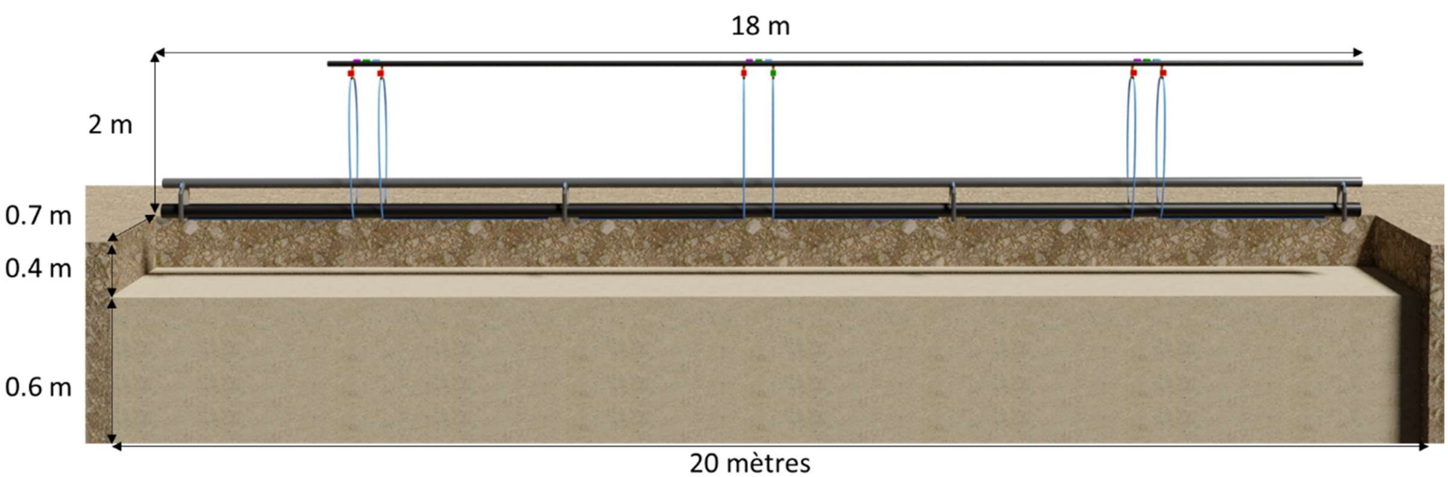


Figure 8 : Diagram of the trench

The flexibility of the chosen tube will ensure the silting of the tube by a 6m section length as shown on the following sketches:

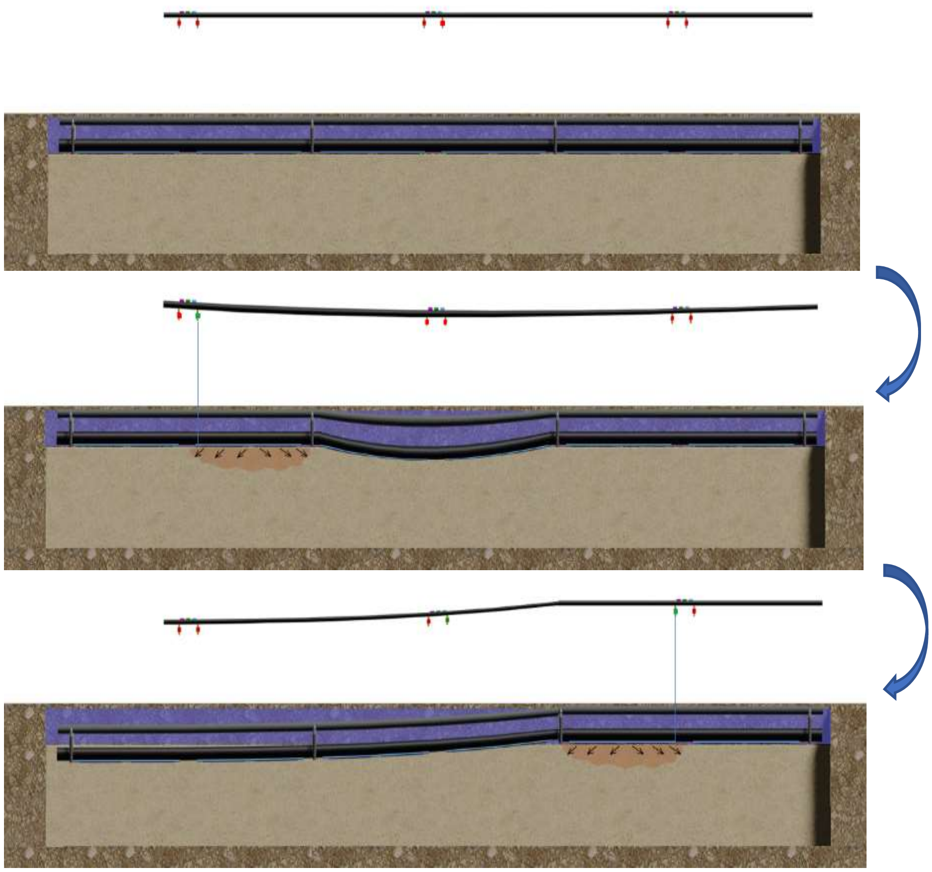


Figure 9 : Diagram of the self-burying

A preliminary analysis performed with RDM7 has confirmed the flexibility of the tube with a deflection of 195mm for the 6m section length.

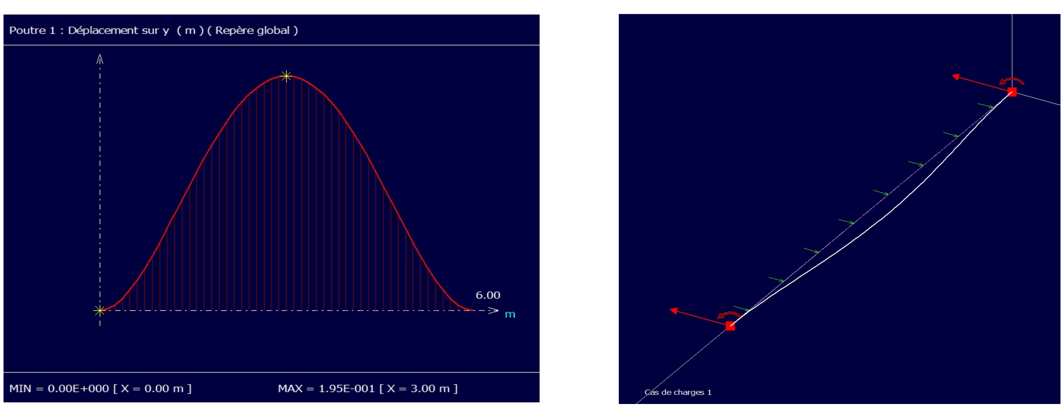


Figure 10 : RDM7 simulation of the SWAC tube flexion including the apparent mass of the ballast

Including the ballast weight, the apparent mass of the immerged pipe is 14,46 kg/m.

7. Prototype description

7.1. Prototype overall description

The prototype shall be equipped with two fluid circuits as shown on the figure below:

- The injection circuit (blue pipes) is responsible for injecting water below the pipe and thus fluidizing the sand. It conveys water under pressure under the tube in the injection modules. Air injection is also achieved through this circuit.
- The second circuit is the recovery circuit of this fluidized sand. It will allow to remove the sandy water under the SWAC tube and thus accelerate its silting.

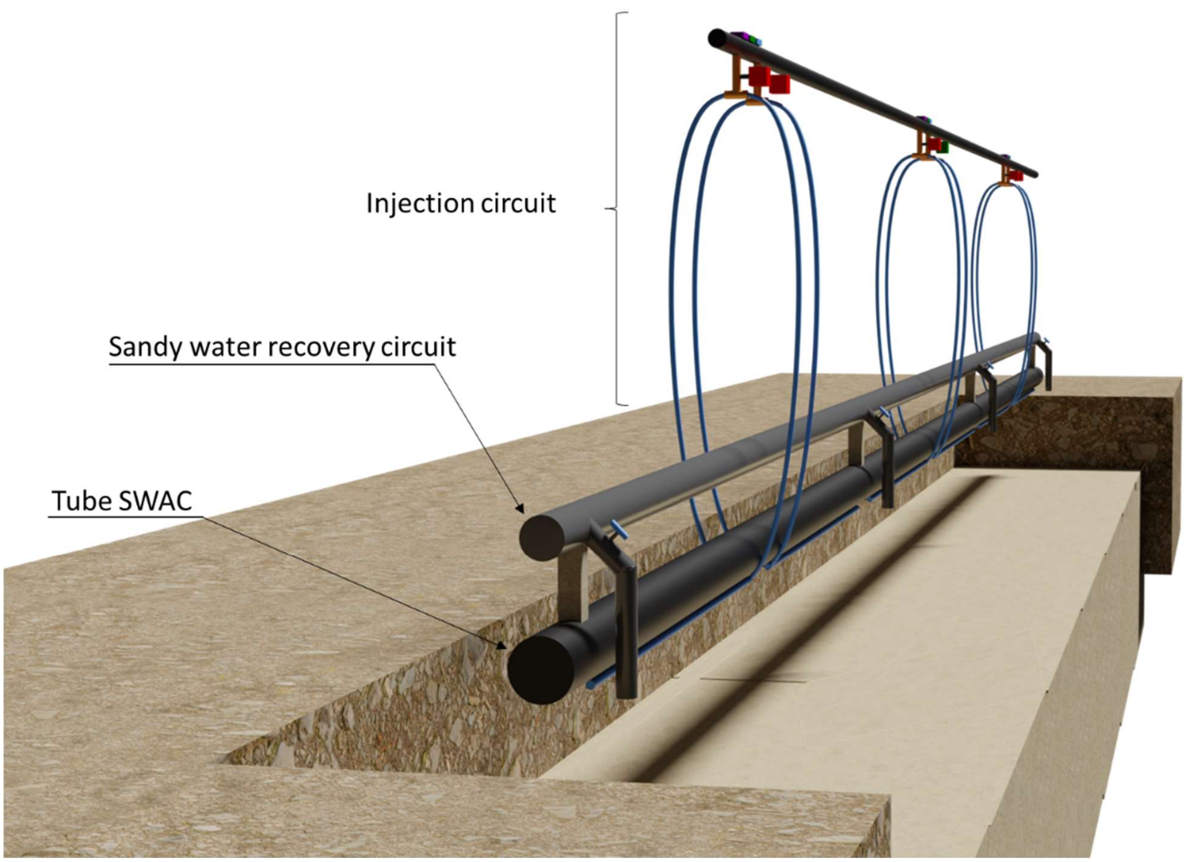


Figure 11 : perspective view of the prototype

As shown on the diagram above, motorized, and manual valves enable to control the 3 sections of the prototype. They allow to select a 3 meters long trench to throw pressurized water on and aspirate the sandy water generated in this manner.

7.2. Injection System principle

The injection circuit in blue is fed by a pump connected to a water source. The water passes through the main tube (the black tube), called the "manifold", and is distributed to each of the "injection modules" through the "dividers". An "injection module" is made up of a "hose", a brass elbow, and the "bar" in which the holes through which the pressurized water jets will exit are drilled (diameter: 2mm). Each bar measures 2.5 meters.

The brown angle is made of steel, it is used to fix the bars to the SWAC tube but also to weight the whole prototype.

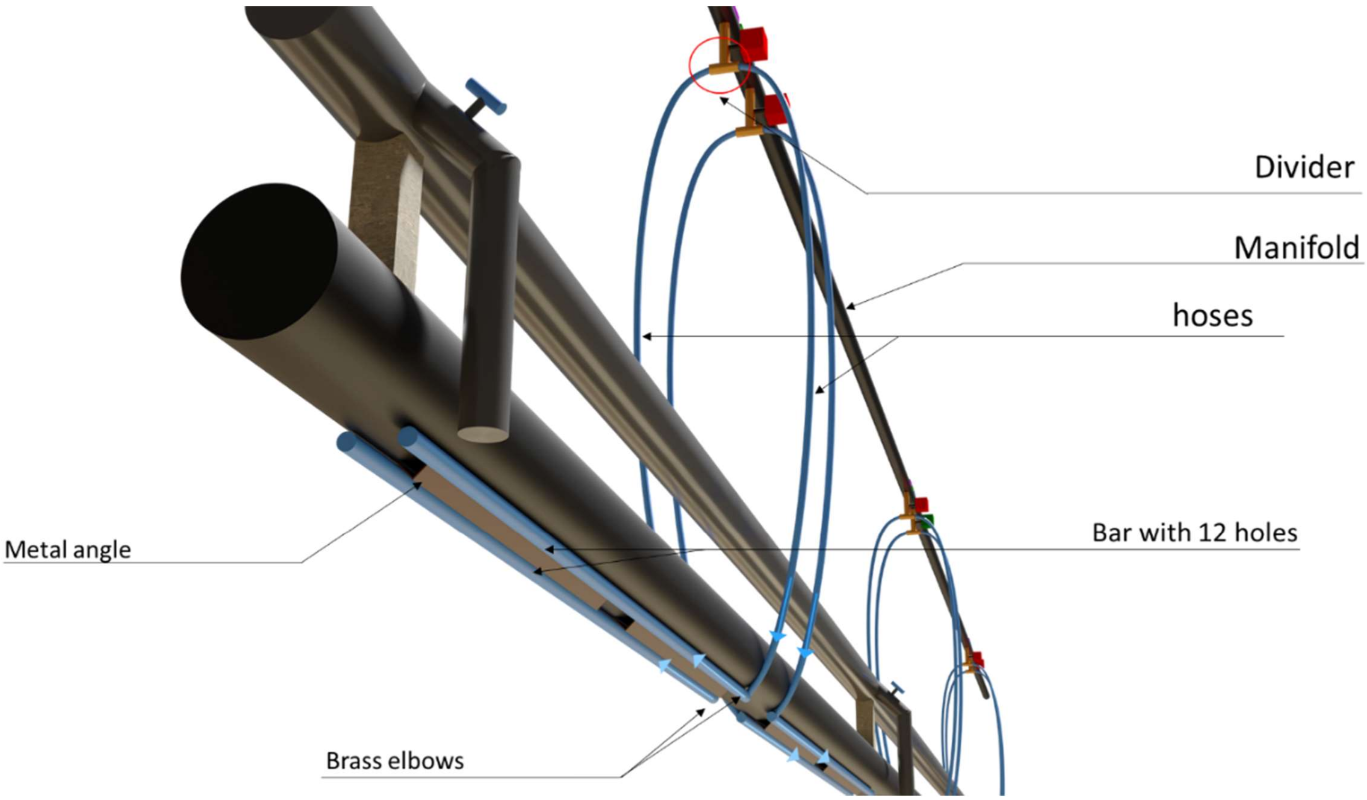


Figure 12 : Injection system

As a first approach, and based on the experience of DeProfundis, 12holes are used for each bar.

7.3. Sand Suction System description

The sand aspiration system in grey is fed by a downstream centrifugal pump. The sandy water passes through the suction pipes, then through the main tube, through the pump and is ejected in the sand tank. The centrifugal pump is not self-priming so that the upstream circuit must be filled of water for the proper functioning of the suction.

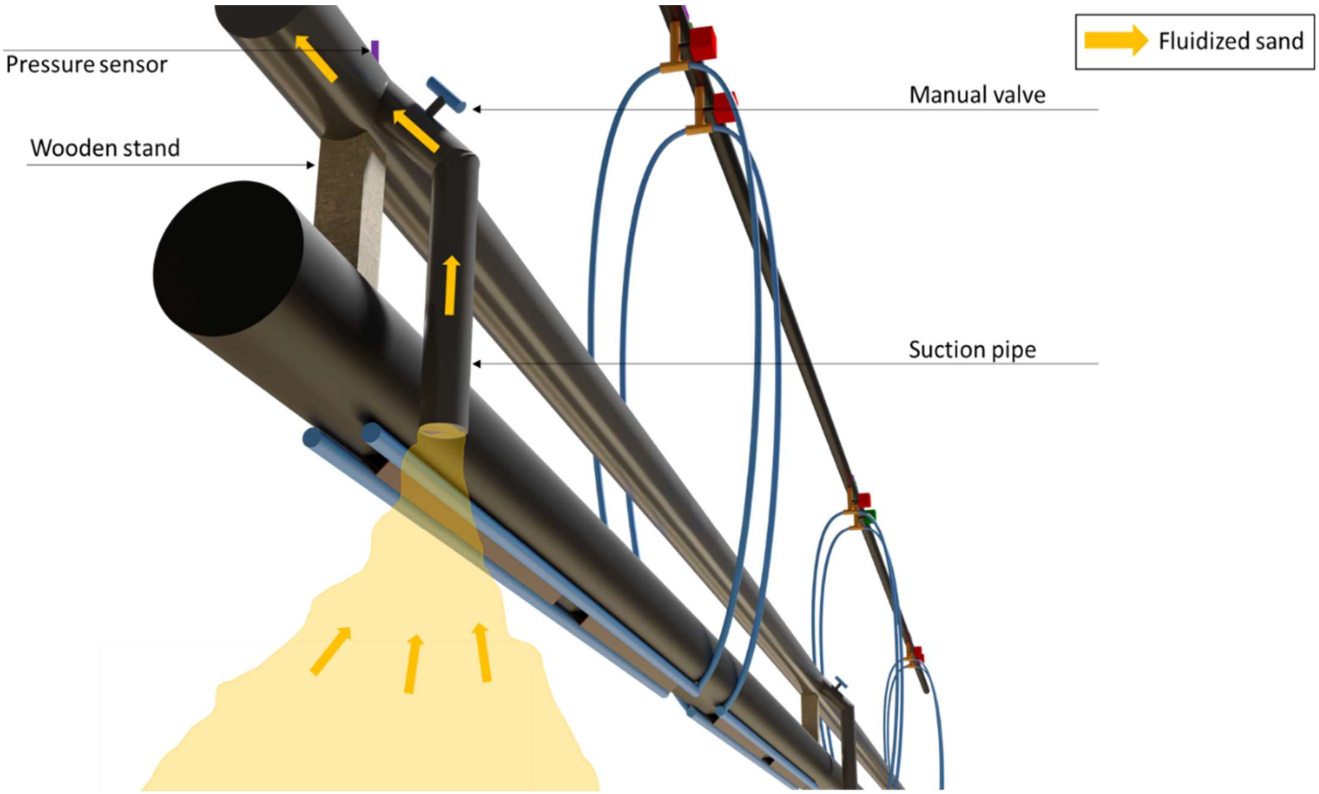


Figure 13 : Sand aspiration system

Each suction pipe (4 in all) is equipped with a manual valve to control the localization of the suction which depends on the localization of the pressurized water injection.

7.4. Dimensions

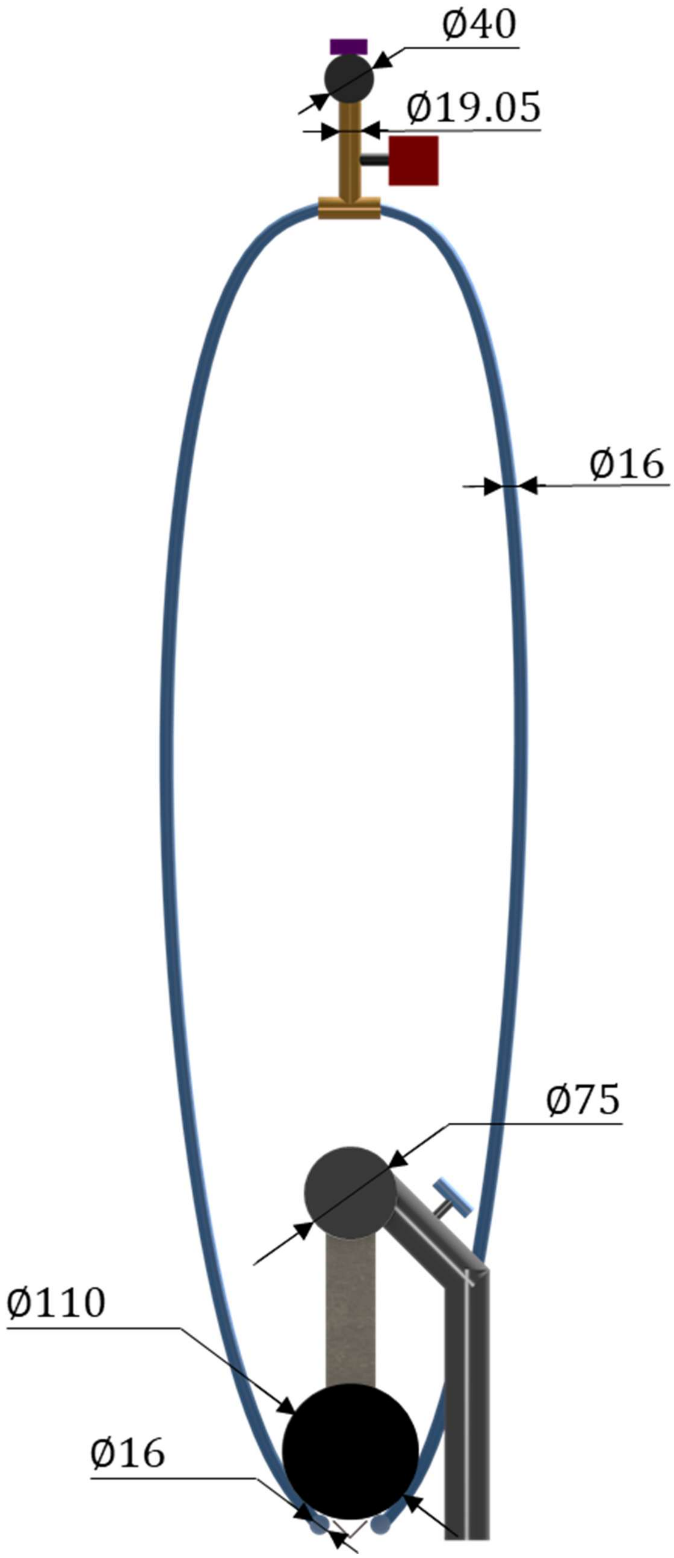


Figure 14 : Dimensions of the prototype (mm)

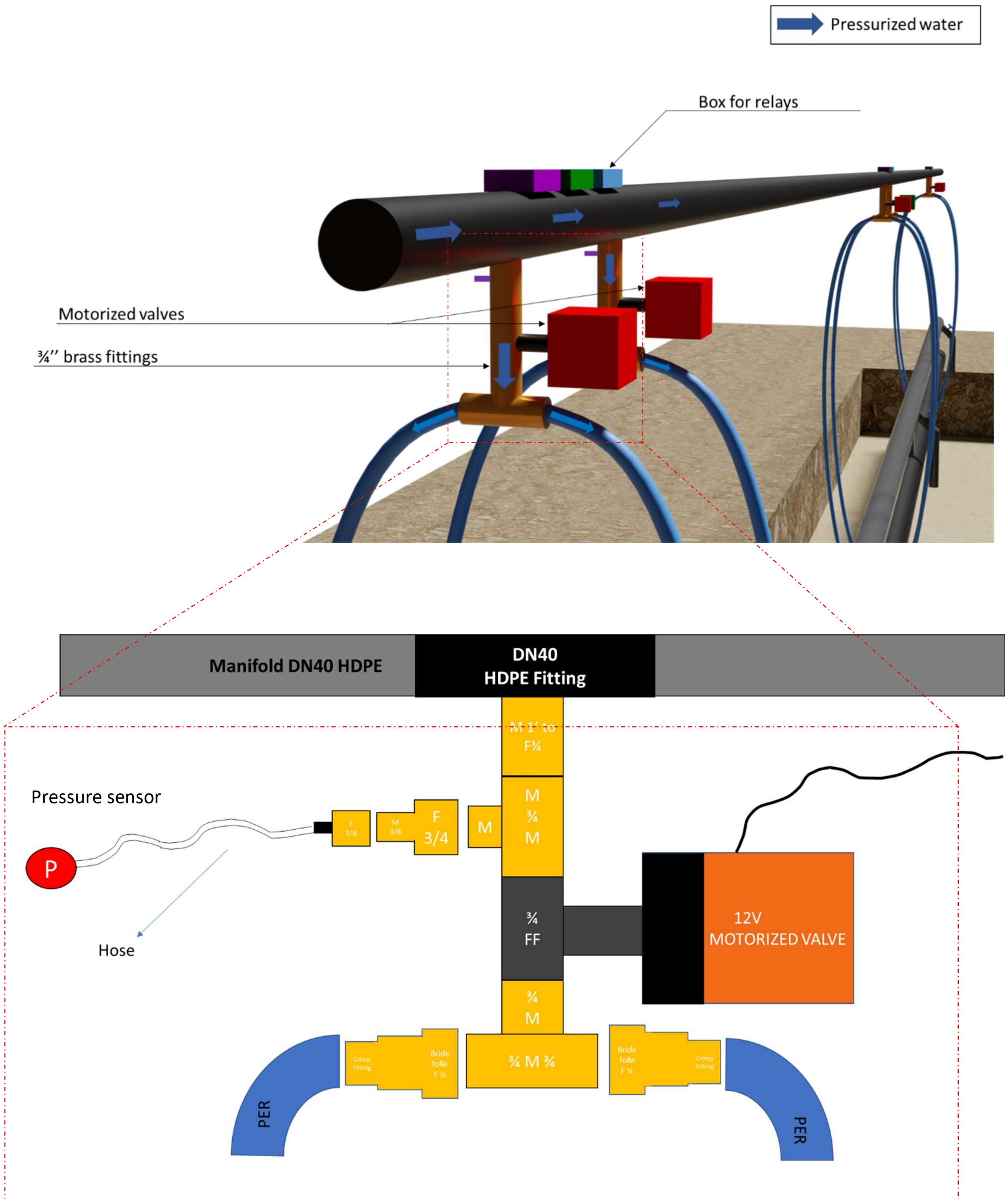


Figure 15 : Divide's diagram

All the fitting in yellow are brass-made.

Systems	Components	Material	Dimensions	Fixations	Quantities	References
SWAC system	SWAC tube	HDPE	DN110 SDR11 Length: 6 meters	plastic connector resistance welding	3	
Injection System	Manifold	HDPE	DN40 length: 3 meters	bullfighting joint	6	
	Connector (manifold)	Plastic / caoutchouc	DN40		6	
	Divider	Brass	Diviseur M3/4 Raccord bride folle F3/4 vers tube souple DN16 Raccord droit M1 vers F3/4 Raccord droit F3/4 vers M3/8 Raccord F3/8 vers trou	Teflon+ joint	6	
	Hose	PER	DN16 length: 2 meters	Crimping on brass connectors	12	
	Bar	PER	DN16 length: 2,5 meters	Crimping on brass connectors	12	
	Elbow	Brass	M1/2 vers tube souple DN16	Crimping on brass connectors Teflon+ joint	12	
	Plugs	Brass	M1/2 vers tube souple DN16	Crimping on brass connectors Teflon+ joint	12	
	Metal angle	Steel	60x8 length: 1 meter	Screw	24	
	Motorized valve	Electric motor	12V FF3/4	Hydraulic circuit Teflon	6	
Suction system	Main tube	Reinforced PVC	DN75 length: 3 meters	PVC glue	6	
	Manual valve	Plastic	DN63	Screw + bullfighting joint	4	
	Suction pipe 63	Reinforced PVC	DN63	PVC glue	4	
	Wooden stand	Wood	20 cm with 2 concave arcs (80 and 110)	Screw	7	

8. Prototype assembly and initial design

8.1. Test site

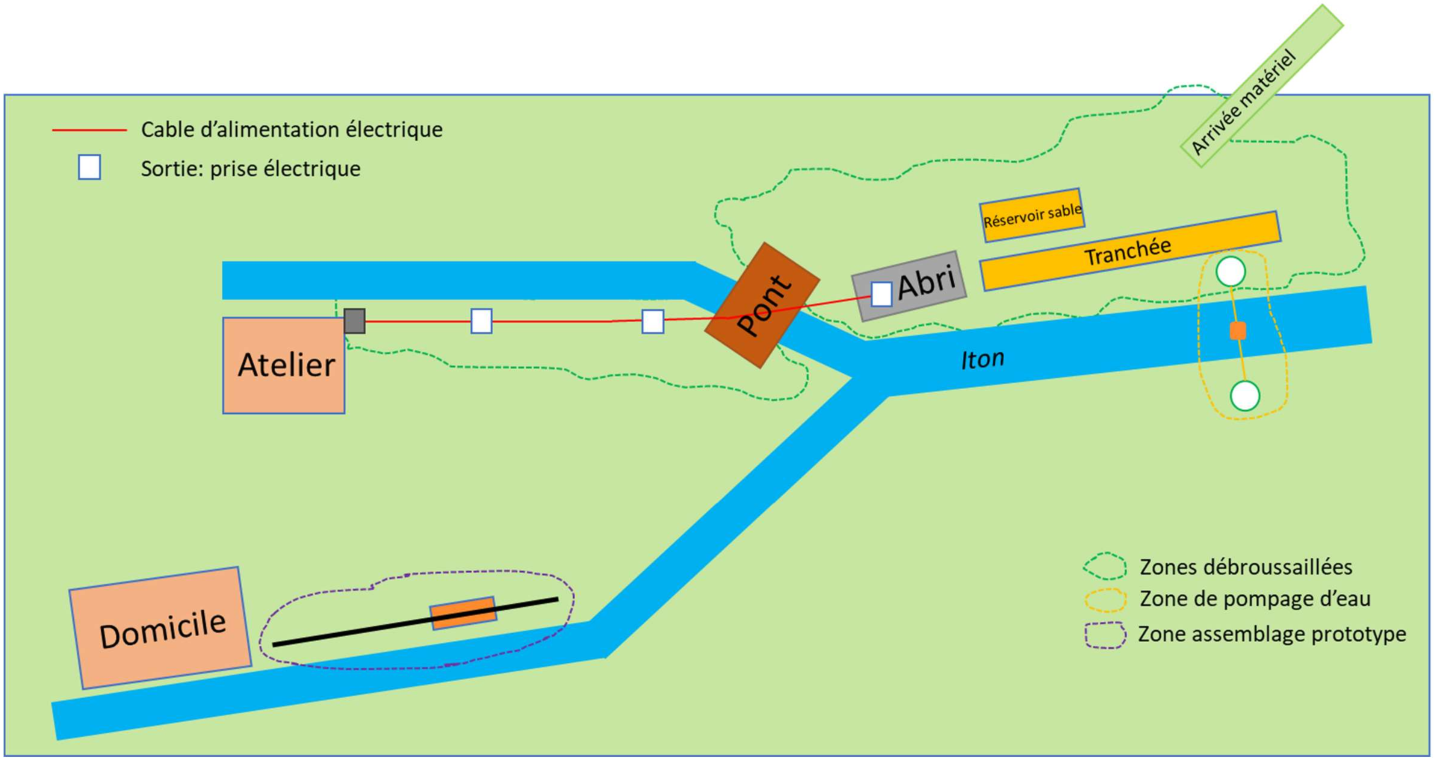


Figure 16 : Plan of the test site at the Moulin du Sacq

The plan above shows the organization of the test site in Normandy. The trench for the tests is 20 meters long, 70 cm wide and 1m deep. 8 m3 of sand have been distributed in the trench, i.e., a sand depth of approximately 60cm.

The sand tank on the plan next to the trench was supposed to be used for storing the sand pumped by the recovery circuit but was finally not used (see section 10.3). A connection between the sand tank and the trench was installed to balance the water level of the two tanks.

8.2. Preparation of the trench

The digging of the trench and the tank took 2 weeks due to the initial choice of a non-optimal machine. A thermal trencher was rented the first week to saw the edges of the trench to facilitate the digging with the excavator. Unfortunately, the soil in Normandy is full of flint stones. The use of the thermal trencher was finally abandoned. The excavator was rented the following week.

Figure 17 : Photos of the trench and tank excavation

A foam protection was installed at the bottom of the trench and a plastic cover were put in place. The purpose of this protection is to prevent the tarp from being pierced by the weight of the sand/water/prototype mixture. The tarpaulin keeps the trench watertight enough to perform the tests.

The trench is installed along the river at 2 meters from it. A porous contact between both was suspected, but no water migration was observed after the realization of the trench.

Figure 20 : Installation of the foam protection in the trench

Figure 19: Laying the tarp in the trench

Figure 18 : Installation of the tarp in the tank and final rendering

8.3. Description and treatment of the sand

The sand used contains very fine particles that cloud the water and limit visibility on the prototype during testing. For this reason, it has been decided to "wash" the sand. An ecological flocculant responsible for making the water more transparent has been added to the sand. It creates precipitates in the water containing these particles, it only remains to pick them up with a dip net. However, to bring out these particles, it was necessary to stir the sand. A system was developed for this purpose:

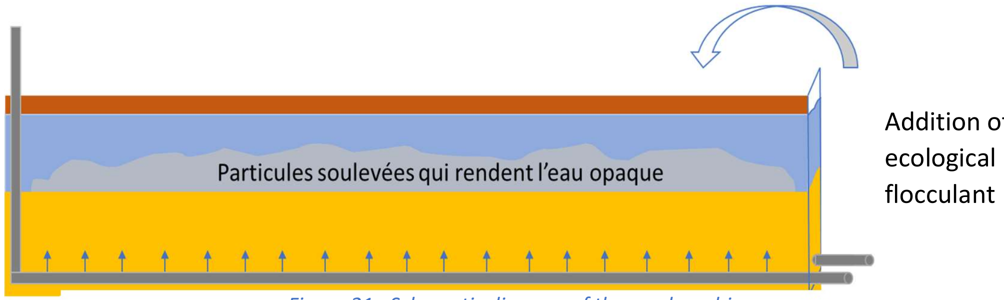


Figure 21 : Schematic diagram of the sand washing process

Two perforated PVC tubes (holes upwards) have been installed in the trench. They have been used to inject water under the sand. As a result, the water has lifted the particles of all the sand contained in the trench.
The realization of drilled tubes and connections was quite fast. The PVC-PVC joint requires the use of a special glue and the rubbing of the ends with abrasive paper to allow a better adhesion of the glue.

Figure 22 : Drilling of injection holes, gluing of PVC fittings and rendering

8.4. Filling the trench

We filled the trench with sand newly bought.

The tarp is not wide enough in certain places of the trench (inaccessible creases under the sand). As a result, it falls back into the trench, which causes water to spill outside, between the earthen walls and the tarp. To remedy this, wooden planks tighten the ends of the tarp over its entire length. Ropes then pull the wooden planks out of the trench.

Figure 23 : Filling the trench and pulling the tarp

8.5. Pump installation

The pump is installed in the water thanks to two ropes: the first rope (blue) hase been attached to two trees in height to suspend a carabiner which will be used as pulley. A second rope (yellow) allows adjustment of the height of immersion from the bank.

Figure 24 : Installation of the pump in the river

8.6. Injection modules assembly

Injection modules was assembled in the workshop.

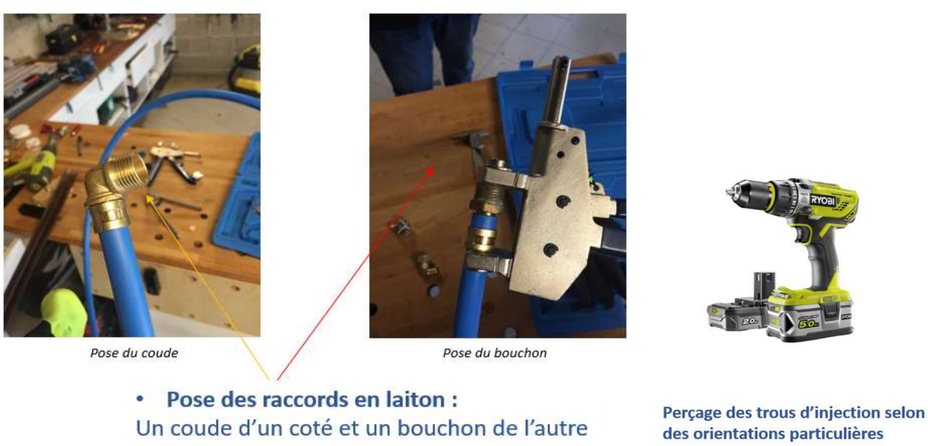


Figure 25: Plumbing

The brass fitting has two parts, the body, and the ring. The ring will clamp the PER pipe to the body. For this purpose, a slip-on clamp is used.

8.7. Outdoor workbench

Formwork in reinforced concrete and breeze blocks. Wooden platform.

Figure 26 : Workbench construction

An outdoor workbench was constructed for prototype assembly and other actions impossible to perform indoor for a matter of dirtiness or healthcare (PVC assembly with toxic glue, chemical coatings etc). The workbench was made in reinforced concrete a breeze blocks with a wooden platform.

8.8. Prototype assembly and handling structure

The assembly of the prototype started at the beginning of July. The injection modules as well as the angle iron have been mounted on the SWAC tube.

Figure 27 : Photos of the installation of the angles and bars on the SWAC tube

As shown these pictures, the angle iron will be divided into 1.5 m long pieces. The objective is to install force sensors under each of them to determine if the prototype touches the sand during the tests. See the section 8.9 for more details.

8.9. Handling devices

The prototype weighing 445 kg, several handling devices must be built. A trellis system is required to install the prototype in the trench and to remove it. A metal structure has been designed to hold everything together. It will consist of 4 brackets spread over the 18 m (as in the image).

Figure 28 : Handling structure

The handling structure is made of steel bars treated with anti-rust and connectors. They form four tripods distributed on the prototype’s length. Three four meters steel angles are placed on the tripods. These structures are used to connect electronic systems, fixation for manifold, structure for lifting the prototype through the intermediary of pulleys.

8.10. Pump priming

The pump is primed with the green pipe as shown on the photo.

Figure 29 : Suction pump

The injection pump in the river is used to fill the upstream suction circuit. The flow that is normally directed to the manifold (in black) is deviated with the use of 2 valves and is injected at the suction pump inlet. The manual valves of the suction circuit are all closed to fill entirely the upstream circuit. When the water starts to be evacuated downstream, the suction pump is turned on and the experimentation can start.

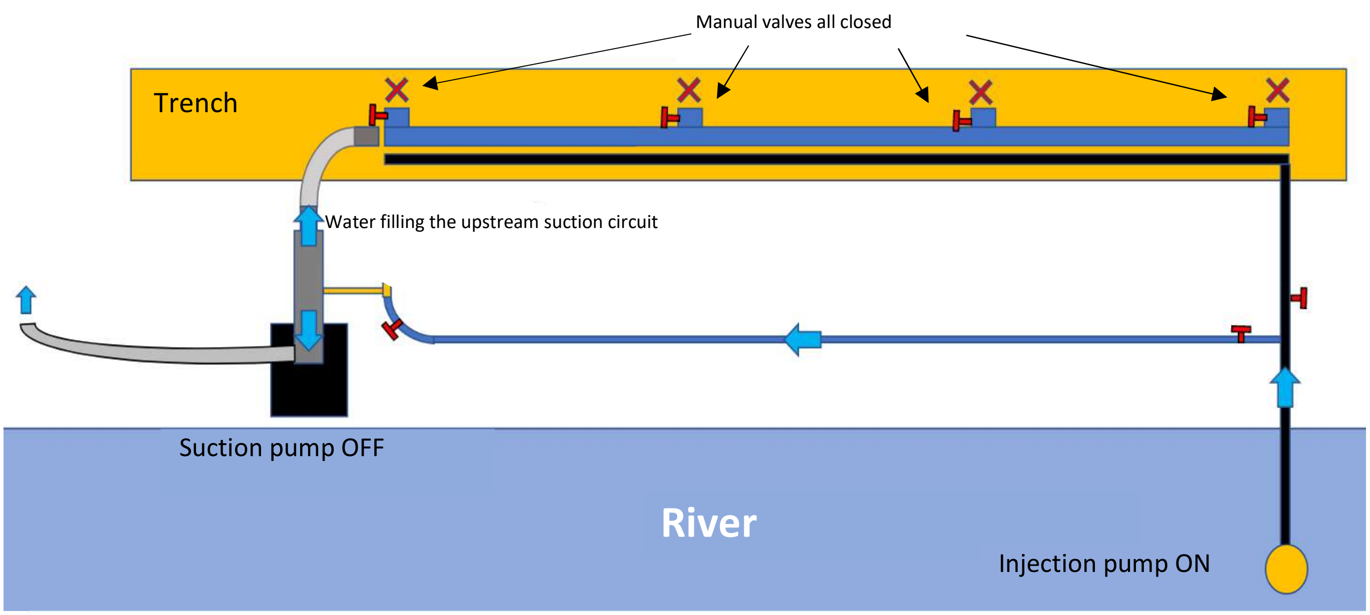
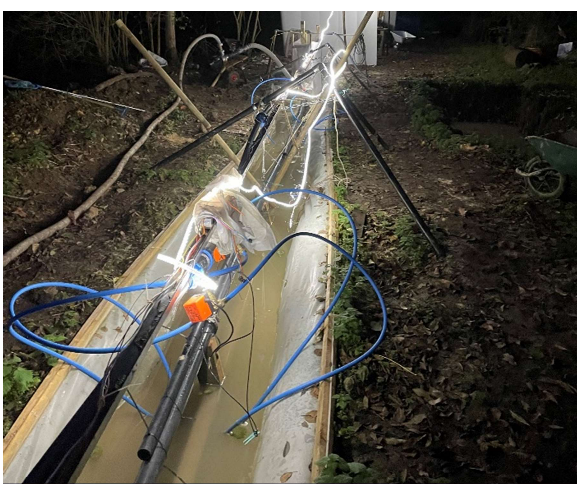


Figure 30 : diagram of the pump priming method

8.11. The system



As the days were getting shorter during November, a LED-made garland was installed

Figure 31 : Pictures of the system

8.12. Electronics and command

The electronics is a very important part of the project, not only for the control of the different elements described below but also for the acquisition of numerous measured data. The sensors and actuators of the prototype are connected to a control and visualization interface on Excel. The objective is to have a very clear and intuitive interface describing the state of the prototype, with on/off buttons for the motorized valves and real-time visualization tables of the silting.

There are more than a hundred electronic components of 9 different types.

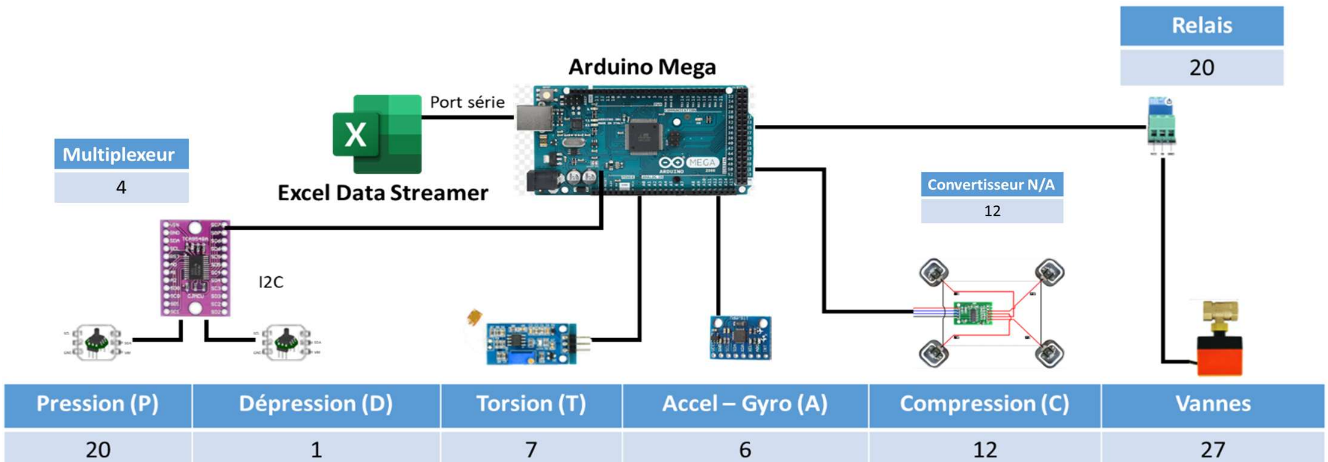


Figure 32 : Summary of the electrical components that equip the prototype

The different sensors are used to monitor the silting of the prototype and to verify the hypotheses formulated in the hydraulic modelling part. Among these types of sensors:

(P) and (D) The relative pressure (and depression) sensor for the injection and suction modules

(A) Accelerometer and gyrometer for the monitoring of the pipe displacement

(C) The force sensor under the hose to track interactions with the ground

(T) A strain gauge that is intended to reflect the flow rate of the water/sand mixture after calibration.

The only actuators present:

Motorized valves for pressurized water injection and fluidized sand suction.

The following diagram is a flat view of the prototype.

It groups all the sensors and actuators present. We distinguish the return and injection circuits in green and yellow respectively. The sensors are represented by red circles and the motorized valves by yellow circles. 12 motorized valves open or close the injection modules. The remaining motorized valves control the pressurized water circuits used to unblock the sand recovery circuit if necessary. The green circles represent manual valves located at each inlet of the recovery circuit.

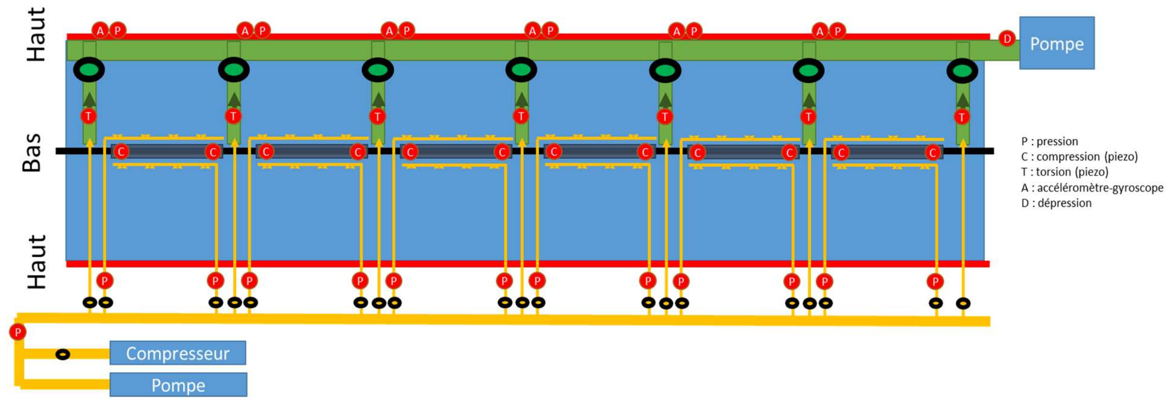


Figure 33 : Flat schematic of the prototype's onboard electronics

8.12.1. Communication protocole

The use of a communication protocol is necessary, it is the language used so that the Arduino board and the computer that must exchange information can do so in an understandable way.

8.12.1.1. Sensors

ID-type-taille_message-message,

The protocol contains the ID of the sensor (ID), its type, the length of data read (in bytes) and finally the data. All these data are separated by dashes. The end of the message is a comma.

At each time interval (predefined), the Arduino board sends on the serial port the concatenation of the data from all the sensors, we can interpret this signal as a table whose boxes are separated by commas that end each message (communication protocol). By convention, the first element of the signal contains two data separated by a dash, the total size of the signal and the number of sensors.

The signal is thus of the form:

Taille_totale-Nombre_capteurs,ID-type-taille_message-message,…,ID-type-taille_message-message,,,…,

The signal is read by the Data Steamer module in Excel. Note: Each signal is a string of characters.

Données entrantes (de Périphérique série USB (COM7))

Les données provenant de la source de données actuelle s'afficheront ci-dessous au fur et à mesure de leur réception.

Données actuelles

TIME	CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8	CH9	CH10
13:39:39,67	0037-003	0-1-3-000	-6-000000	-3-4-4029						

Données historiques

TIME	CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8	CH9	CH10
13:38:21,13	0037-003	0-1-3-000	-6-000000	-3-4-4029						
13:38:21,41	0037-003	0-1-3-000	-6-000000	-3-4-4029						
13:38:21,64	0037-003	0-1-3-000	-6-000000	-3-4-4029						
13:38:21,89	0037-003	0-1-3-000	-6-000000	-3-4-4029						
13:38:22,15	0037-003	0-1-3-000	-6-000000	-3-4-4029						
13:38:22,40	0037-003	0-1-3-000	-6-000000	-3-4-4029						
13:38:22,65	0037-003	0-1-3-000	-6-000000	-3-4-4029						
13:38:22,90	0037-003	0-1-3-000	-6-000000	-3-4-4029						
13:38:23,15	0037-003	0-1-3-000	-6-000000	-3-4-4029						
13:38:23,42	0037-003	0-1-3-000	-6-000000	-3-4-4029						
13:38:23,66	0037-003	0-1-3-000	-6-000000	-3-4-4029						
13:38:23,91	0037-003	0-1-3-000	-6-000000	-3-4-4029						
13:38:24,16	0037-003	0-1-3-000	-6-000000	-3-4-4029						
13:38:24,41	0037-003	0-1-3-000	-6-000000	-3-4-4029						
13:38:24,66	0037-003	0-1-3-000	-6-000000	-3-4-4029						

◄ Plus récent

Interface Graphs | Interface Split | Données physiques | Données entrantes | Données sorta ...

Figure 34 : Interface of Data Streamer on Excel which displays the signal at regular intervals

A VBA code then decodes each protocol, classifies the data, and returns the whole in the table of an Excel sheet.

	A	B	C	D
1	Réinitialise	0	1	2
2		000	000	255
3				
4				
5		OK		
6	N° capteur	0	1	2
7	Donnée 1	0	0	40
8	Donnée 2		0	29
9	Donnée 3			
10	Donnée 4			
11	Donnée 5			
12	Donnée 6			
13				

Interface Graphs | Interface Split | Données physiques | Données entrantes | Données sortantes | Paramèt

Figure 35 : Table of data once processed by the Excel macro

The yellow table updates the data for each sensor. We can then use this data to create the visualization interface that will give us a very clear view of the state of the prototype.

8.12.1.2. Actuators

The protocol is very similar to that of the sensors. However, unlike the sensors, the protocol is sent from Excel to the Arduino board which will process the instruction and activate a relay that will open or close the motorized valve.

8.12.2. User interfaces

8.12.2.1. Implementation of sensors and actuators (C++ code)

The commands *capteurs.add(type,Pin1,Pin2)* and *commandes.add(type,Pin)* allow to implement a sensor and an actuator respectively.

```
cCapteurs capteurs;                 Initialisation des variables de capteurs et commandes
cCommandes commandes;
int result=1;                       Prendra la valeur de retour de la lecture

void setup() {
  setupArduino_Serial();            Initialisation de la connexion au port série
  capteurs.add(1,A1); capteurs.add(2,A2,A3); capteurs.add(3,2);       Déclarations des capteurs
  commandes.add(1,7); commandes.add(1,8); commandes.add(1,9);   } Déclaration des commandes

void loop() {
    if (UneSeconde()) {             Toutes les secondes
      capteurs.envoi();             On envoie les données des capteurs
      result=commandes.recois();    On lit le port série
      while(result!=0){             En cas d'erreur on relit jusqu'à ce que l'opération réussisse
                                    ou que le Port est vide
        if (result<0){   Serial.println(result);   }
        result=commandes.recois();
}  }  }
```

Figure 36 : Interface Arduino | En vert les lignes pour ajouter des capteurs et actionneurs

class	type	nom
capteurs	3	humidity and temperature
capteurs	4	accelerometre, gyroscope and temperature
capteurs	5	Pressure and temperature
capteurs	6	Weight

class	type	nom
Actionneurs	1	Motorized valve

Figure 37 : Table summarizing the different types of sensors and actuators in the prototype

The sensors and actuators are connected to the Arduino board by one or two wires. Pin1 and Pin2 are the pins for connecting to the board.

8.12.2.2. Excel interface

Once the sensors are implemented in the code and connected to the Arduino board, everything happens on the Excel interface. This interface allows on the one hand the very condensed visualization of the state of the prototype. It also allows to open/close the motorized valves.

Figure 38 : Excel interface for visualization and control of the prototype | Legend

8.12.3. Instrumentation

8.12.3.1. Motorized valves

The 6 valves are controlled by the Arduino board via relays in the blue box on the diagram.

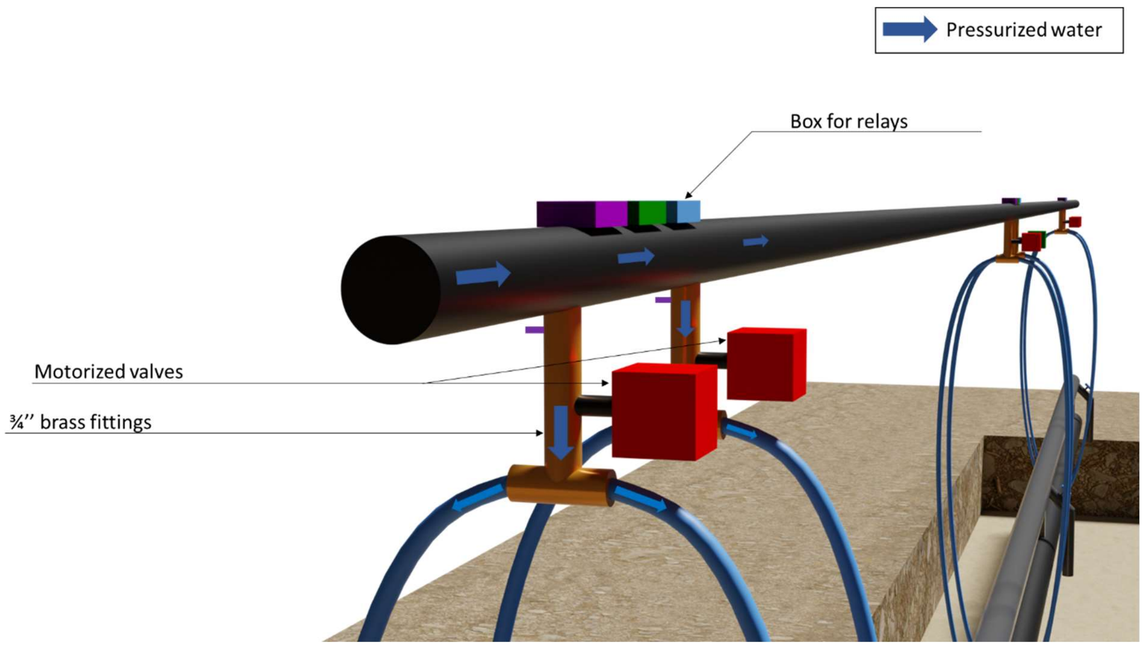


Figure 39 : Photo of the pump ordered

8.12.3.2. Pressure sensors

For economy reasons, the selected pressure sensor can only be used to measure pneumatic pressure and not hydraulic pressure. The following device is used to convert the hydraulic pressure of the water flow into pneumatic pressure:

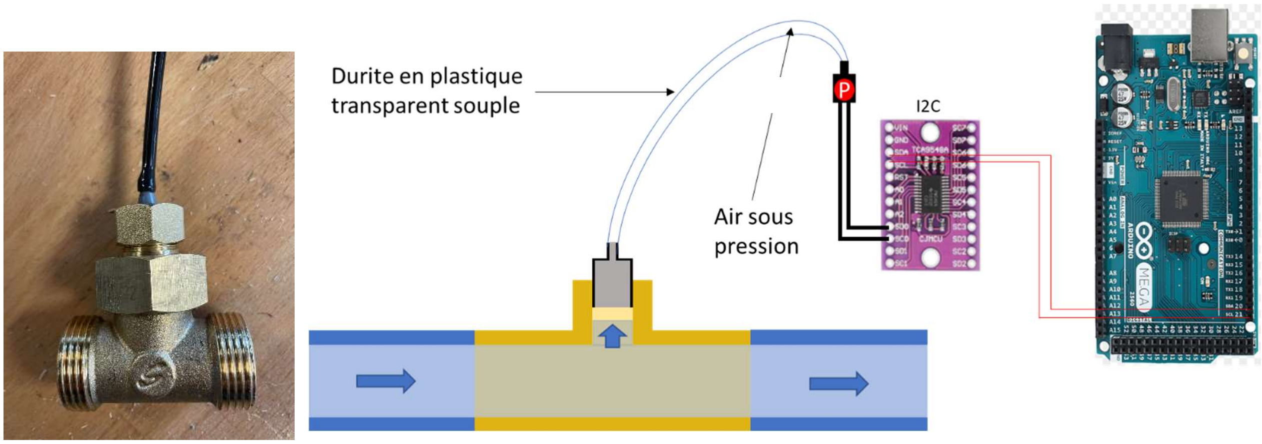
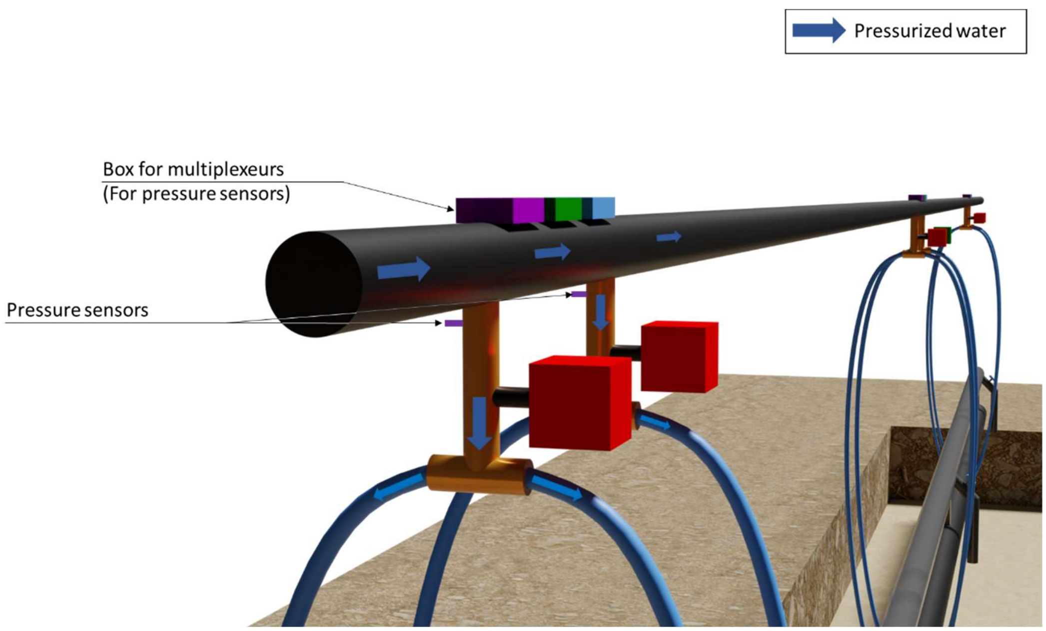


Figure 40 : Schematic diagram of the pressure sensor

The sensor is connected to the water flow by a plastic hose. The stronger the flow, the more the water will rise in the hose and compress the air trapped inside. The difficulty lies in determining the optimal solution for sealing the sensor.



The sensor is calibrated using a bicycle pump equipped with a reliable pressure gauge.

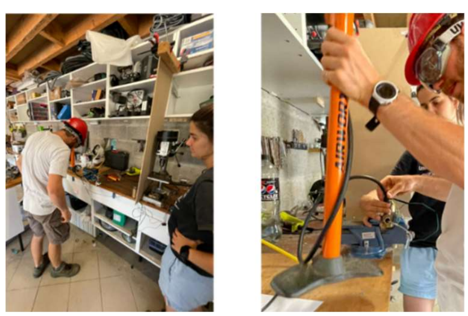


Figure 41 : Photos of the calibration

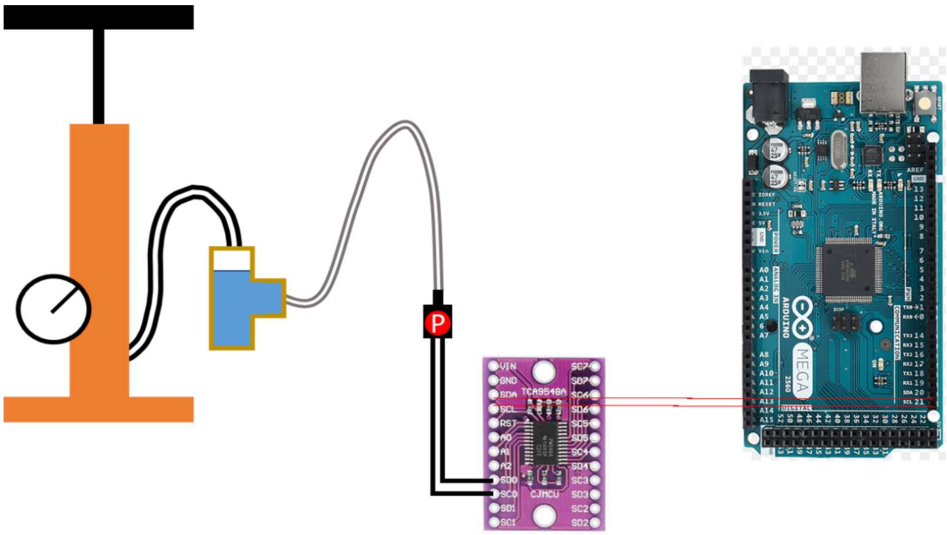


Figure 42 : Diagram of the calibration method

8.12.3.3. Electronics

As there are many pressure sensors on the prototype, it is impossible to connect them all to the Arduino board directly. Moreover, the sensors of the same type have the same address, so they are not differentiable by the I²C bus of the Arduino board. To overcome this problem, we connect all the pressure sensors to multiplexers that can contain up to 8 sensors. Each multiplexer is then connected to the I²C bus of the Arduino board via the SCA/ SCL pins. The I²C bus can manage a maximum of 127 addresses.

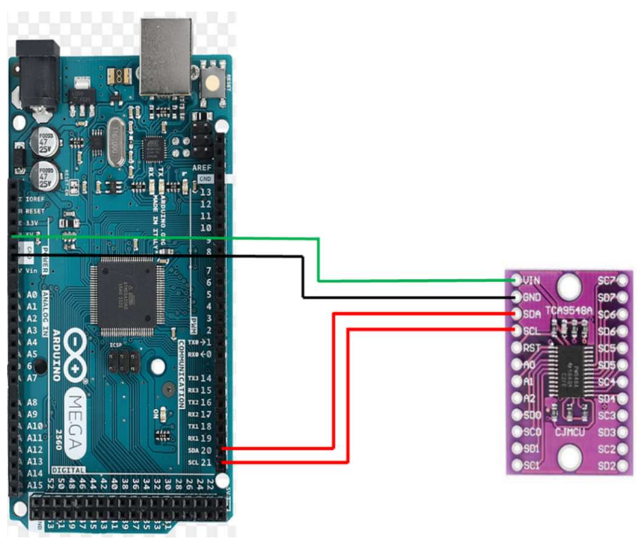


Figure 43 : Connection diagram of the multiplexer to the board

Complement: Each multiplexer is differentiated using pins A0, A1, A2 in which we apply a potential either zero or 5 volts. This gives 8 possible combinations of addresses. We can therefore connect a maximum of 8 multiplexers to the Arduino board.

MUX ADDRESS			
A0	**A1**	**A2**	**I²C Address correspondant**
LOW	LOW	LOW	0x70
HIGH	LOW	LOW	0x71
LOW	HIGH	LOW	0x72
HIGH	HIGH	LOW	0x73
LOW	LOW	HIGH	0x74
HIGH	LOW	HIGH	0x75
LOW	HIGH	HIGH	0x76
HIGH	HIGH	HIGH	0x77

Figure 44 : Table of possible addresses of multiplexers connected to the Arduino

8.12.3.4. Vacuum sensors

The vacuum sensor is the same model as the pressure sensor used. Placed just before the sand pump, it will measure a negative pressure difference. The principle is therefore the same.

To calibrate the sensor, a manual priming pump is used to create a vacuum in the tube with the following configuration:

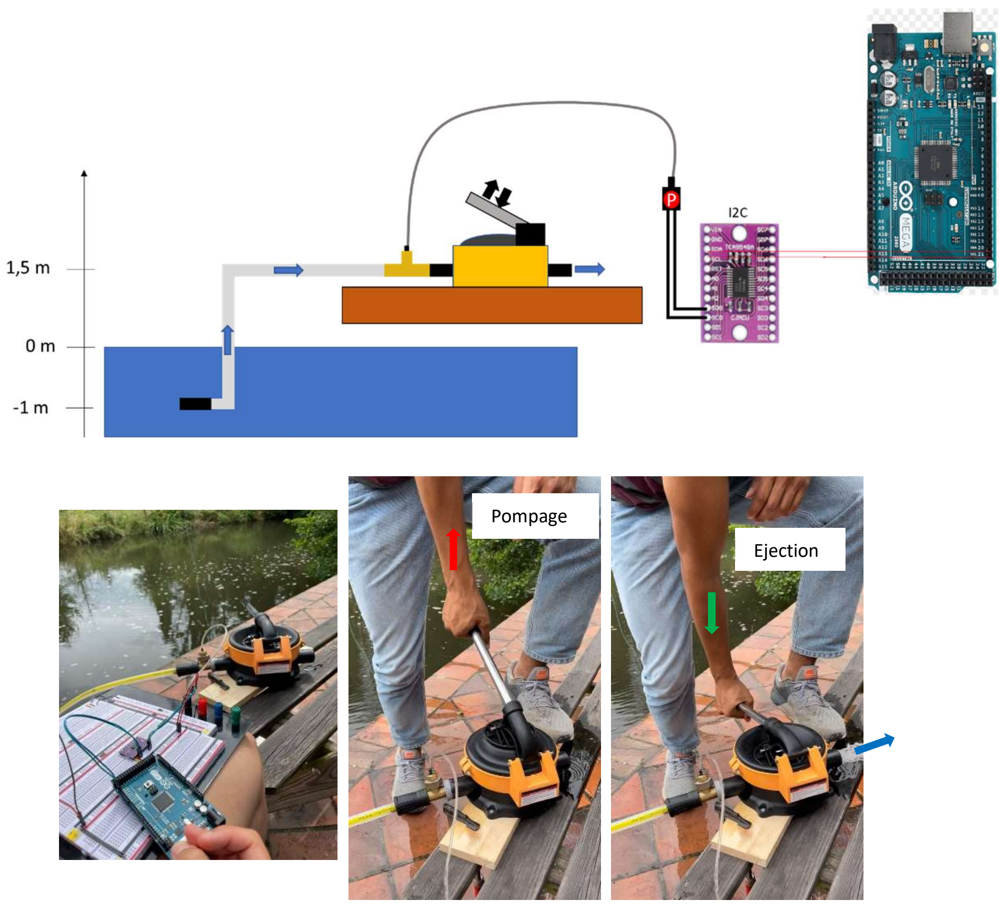


Figure 45 : Diagram and pictures of the vacuum sensor calibration

Two values are important, the value of the sensor at atmospheric pressure and the one after pumping. The sensor is located at 1.5 meters above the water, the value of the absolute pressure after pumping corresponds to the pressure under 1.5 meters of water column, that is 0.15 bar. In our case, -0.15 bar because it is a vacuum.

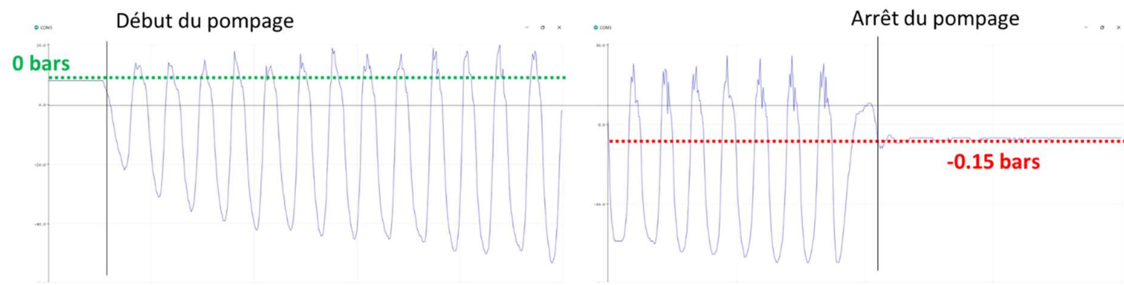


Figure 46 : Serial port signal illustrating the calibration principle

We can therefore shift the 0 and perform a cross product to calibrate the sensor.

Note: This method could very well have been used to calibrate pressure sensors. The method is also more reliable than using a bicycle pump. As the priming pump was bought afterwards, I wanted to show you both methods. In the future, we will calibrate the pressure sensors with this method.

8.12.3.5. Flow sensors

It is important to have an estimate of the flow rate of fluidized sand pumped through the recovery circuit. A conventional flow meter will not be used for two reasons:

- The price of a flow sensor is too high and totally out of budget.

- Sand grains can damage the sensor

An indirect and much less expensive solution is preferred: A strain gauge is attached to a flexible metal plate. This one is fixed to the wall of the recovery tube. The pumped sand grains will hit against the metal plate and apply a stress. We will simply measure this stress with the gauge to try to quantify the volume of fluidized and pumped sand.

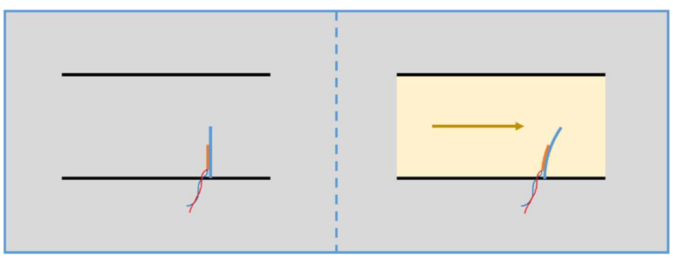


Figure 47 : Principle of the sand flow sensor

The calibration will be done on the prototype directly.

8.12.3.6. Accelerometer-gyrometers

Six accelerometer-gyrometers are placed on the prototype to monitor the silting. All are calibrated. I did not contribute to this task.

8.12.3.7. Compression sensors

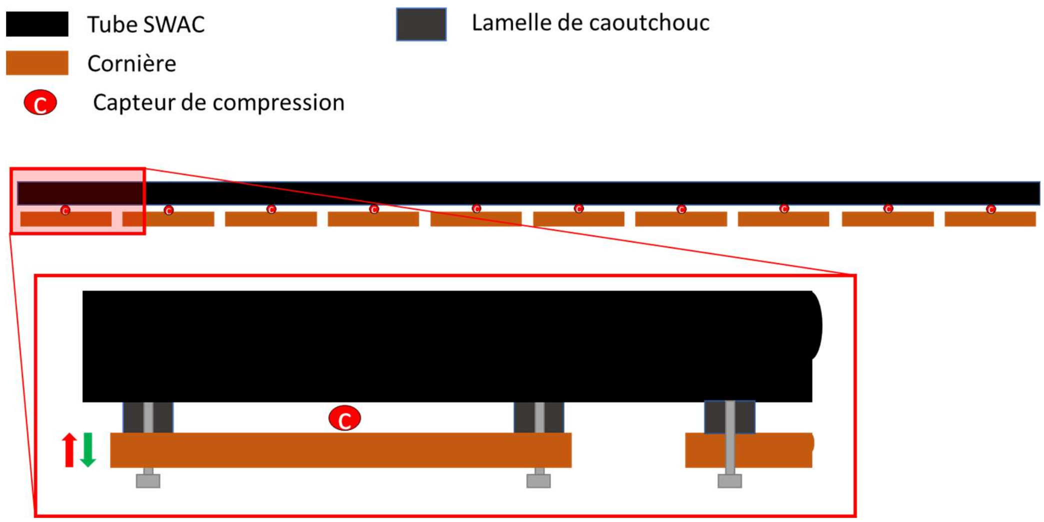


Figure 49 : Installation diagram of the compression sensors

These compression sensors will be used to determine if the prototype is touching the sand or not and also to detect obstacles (e.g. stones) that would prevent the pipe from being embedded. This measurement is important because it will be used to follow the embedding. The angle is cut into 12 pieces of 1.5m (two per injection module). Each angle is fixed by two screws embedded in the SWAC pipe and mounted with clearance in the angle so that the angle can slide along the vertical axis. Rubber strips separate the SWAC tube from the angle. The compression sensor is attached to the angle. It is a compression sensor; it measures a stress in a material and sends back an electric potential to the Arduino board. The captor is attached to a metal plate on which we apply a stress normal to it. A hole is drilled at the end of this plate, the hole is tapped to screw a nut whose flat head will press against the SWAC tube as follows:

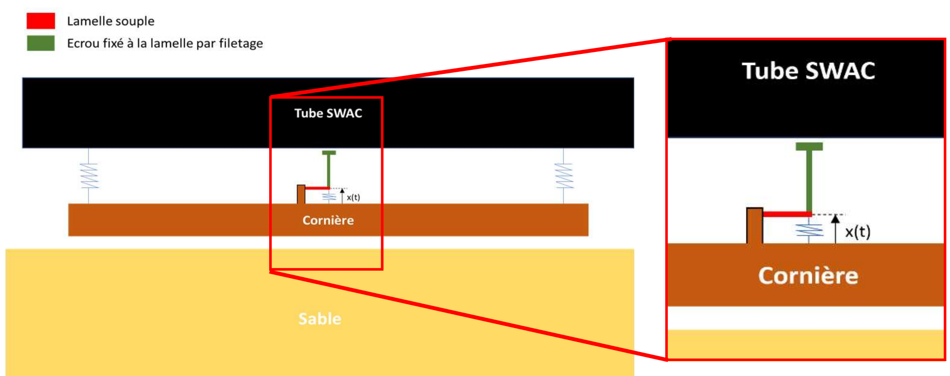


Figure 48 : Diagram of principle

When the prototype settles against the sand, the angle bars mounted with play will slide along the vertical axis and press against the rubber lamellas. The nut head in the middle of the angle will touch the SWAC tube, the flexible lamella will bend, and a potential will be created at the terminals of the piezoelectric material.

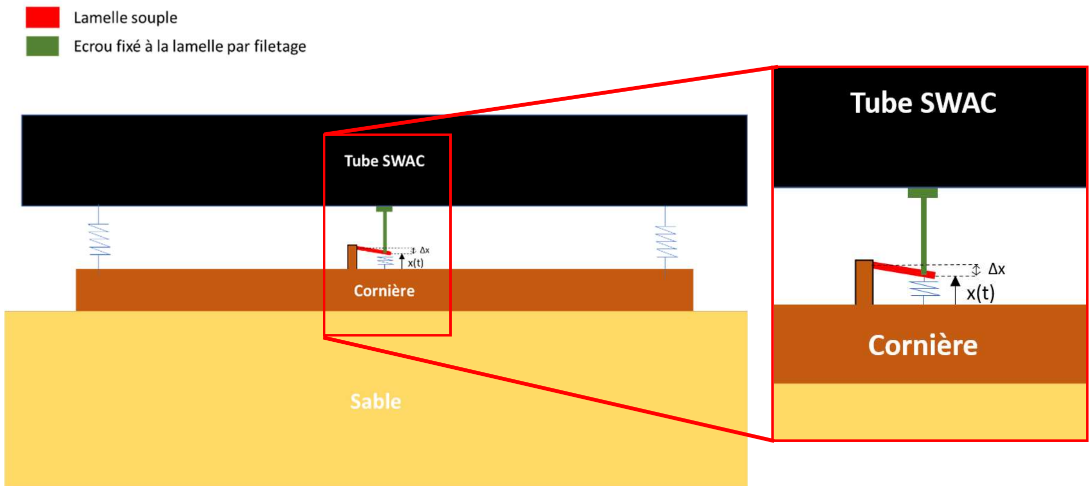


Figure 50 : Diagram of principle

The sensor is fixed to the angle with 4 serflex:

Figure 51 : Photos

i. Electronic assembly

The connection of the sensor to the board is not direct, it is made via a digital/analog converter as follows:s

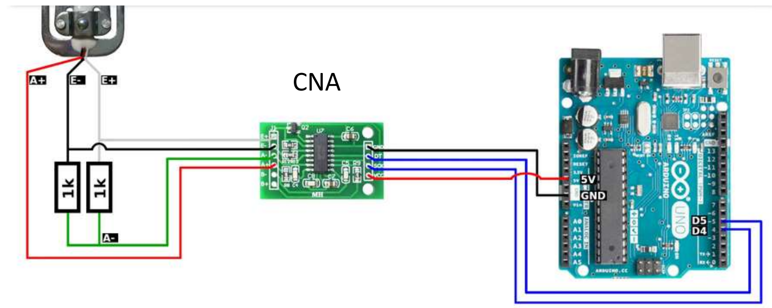


Figure 52 : Electronic assembly diagram

ii. Calibration

Knowing the linear mass of the SWAC tube (in PER), it is easy to perform the calibration. The calibration of all the compression sensors will be done at the same time on the assembled prototype. It will be enough to launch the specific code of calibration for each sensor. In this one, two steps:

- Determine the no-load value of each sensor, i.e., with the tube immersed without touching the bottom
- The loaded value of each sensor, i.e., with the immersed prototype placed on the sand of the trench.

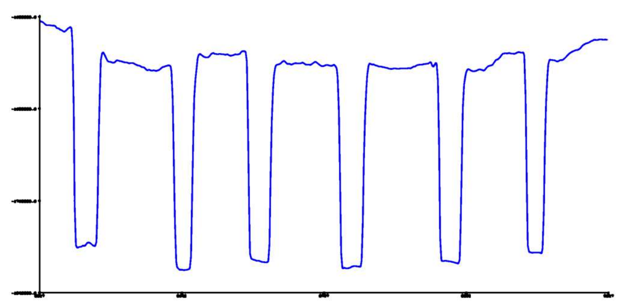


Figure 53 : Signal received from the sensor, alternating between no-load and loaded assembly

iii. Tests with the injection bar

As stated previously, we were rightly concerned that the pressurized water in the system would generate significant vibrations throughout the prototype. If these concerns were true, the vibrations would interfere with the measurement of the compression sensors. We wanted to have an idea of the extent of these vibrations on the measurement. So, a device was set-up to test this hypothesis.

Figure 54 : Photos of the system

An injection module was attached to the SWAC tube with a single angle and the compression measurement device. The injection module is directly attached to a pump. The test was conclusive, no vibration is detected by the sensor which is good news. It remains to be determined whether the sand recovery circuit generates significant vibrations.

iv. Erratum

It appeared during the first tests that the distance between the tube and the angle was too large so that the blown sand was redeposited into it. As it would be very constraining to achieve series and series of test in the water that could damage and test rapidly the exposed parts of the system, it was decided to remove those captors.

8.13. Electronic assembly on the prototype

The prototype assembly led to pragmatic choices regarding the use or not of the captors described in the previous part.

The flow rate captor was eliminated due to a technical problem preventing to make it work correctly in a limited time. The accelerometer-gyrometer has been cancelled as well due to a matter of precision, a simpler solution was chosen. It is possible to measure the silting in real-time using the ropes used to lift the prototype. Two pulleys are linked by the rope. The lowest one is attached to the prototype by another rope. When the prototype dives in the trench, the distance between the two pulleys increases. A simple marker on it permits to easily read the value.

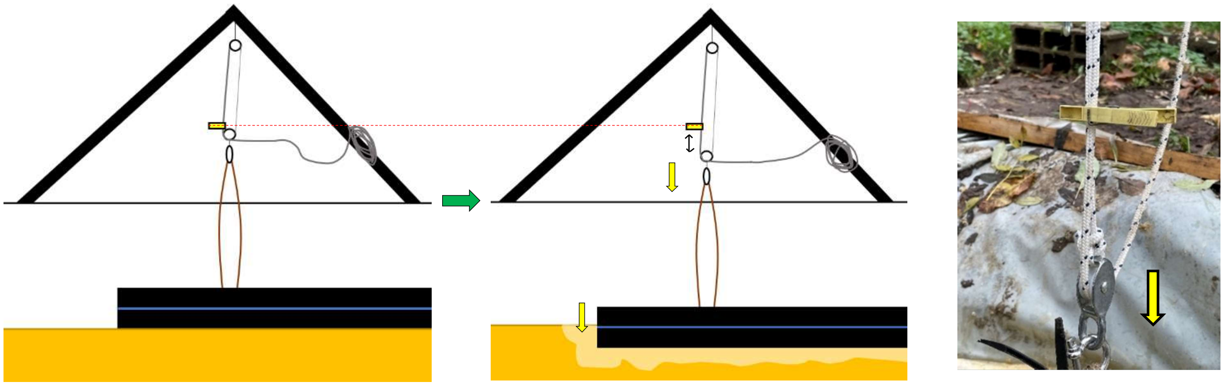
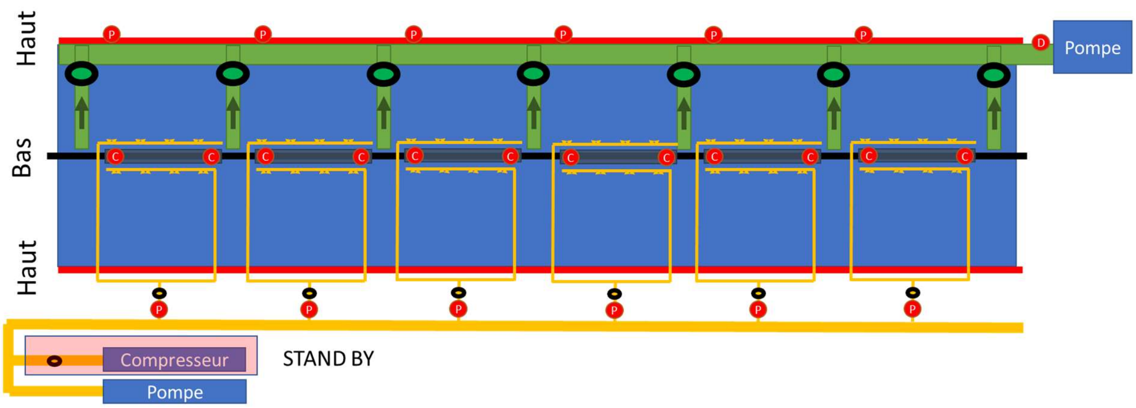


Figure 55 : Sketch of the method

The selected captors were the most important ones: the pressure/ depression captor and the compression captor. It makes 3 electronic components with the motorized valves I need to connect with the control/command system. The updated diagram is now:



Those tree components are connected to the Arduino through few electronic components: The pressure captor must be connected through a multiplexer (MUX), the compression captor through a digital/ analogic convertor and the motorized valve through a relay and powered with a 12 Volts generator.

An additional constraint is added, the electronic boxes on the prototype were selected at the minimum cost. They are 11x6 cm² surface which is very little. I had to optimise the electronic design to fit everything. The connections are made on bread boards.

Note for the next parts: the 5V (VCC) and Ground cables from the Arduino card are respectively colored in red and black. They are always the outgoing ones from the box. The other outgoing cables are whether information cables that go directly to a pin of the Arduino card, whether cables going to the captors / actuators.

8.13.1.1. Compression captor

In this disposition, 2 CNA can be added in the same box that links 4 compression captors. Thus, only 3 boxes are required for all the captors. The resistors on the diagram are 1K Ohm.

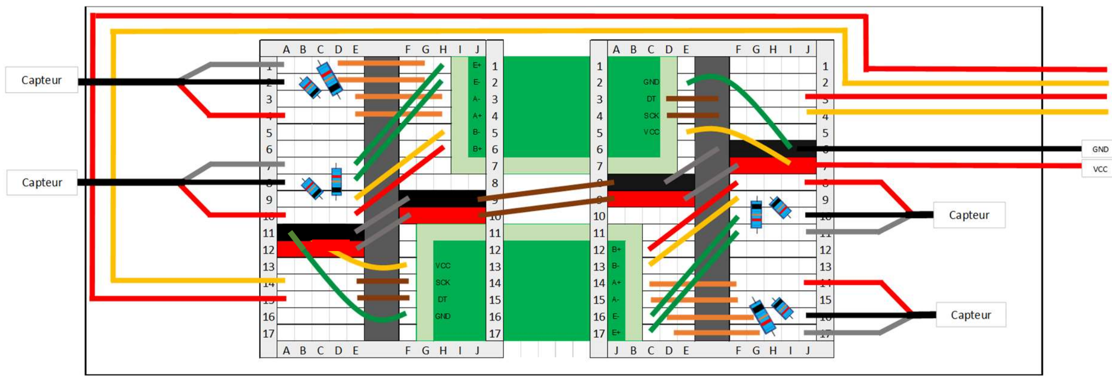


Figure 56 : Electronic diagram of the electronic card

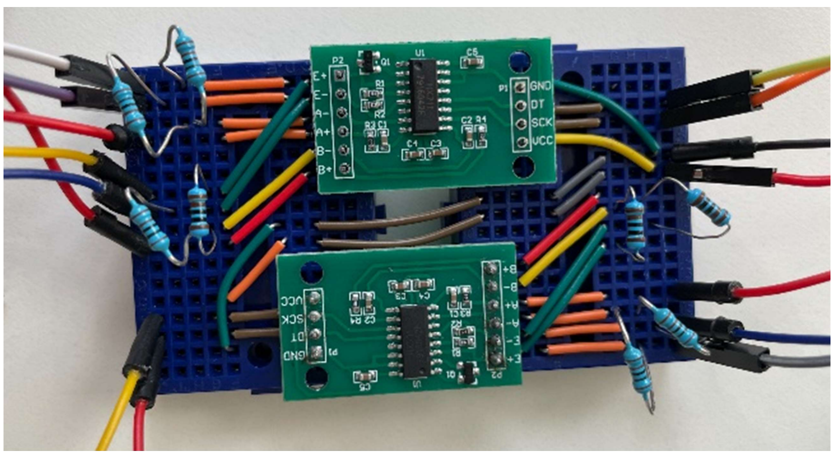


Figure 57 : picture of the electronic card

8.13.1.2. *Pression captor*

4 pressure captors can be added in each box.

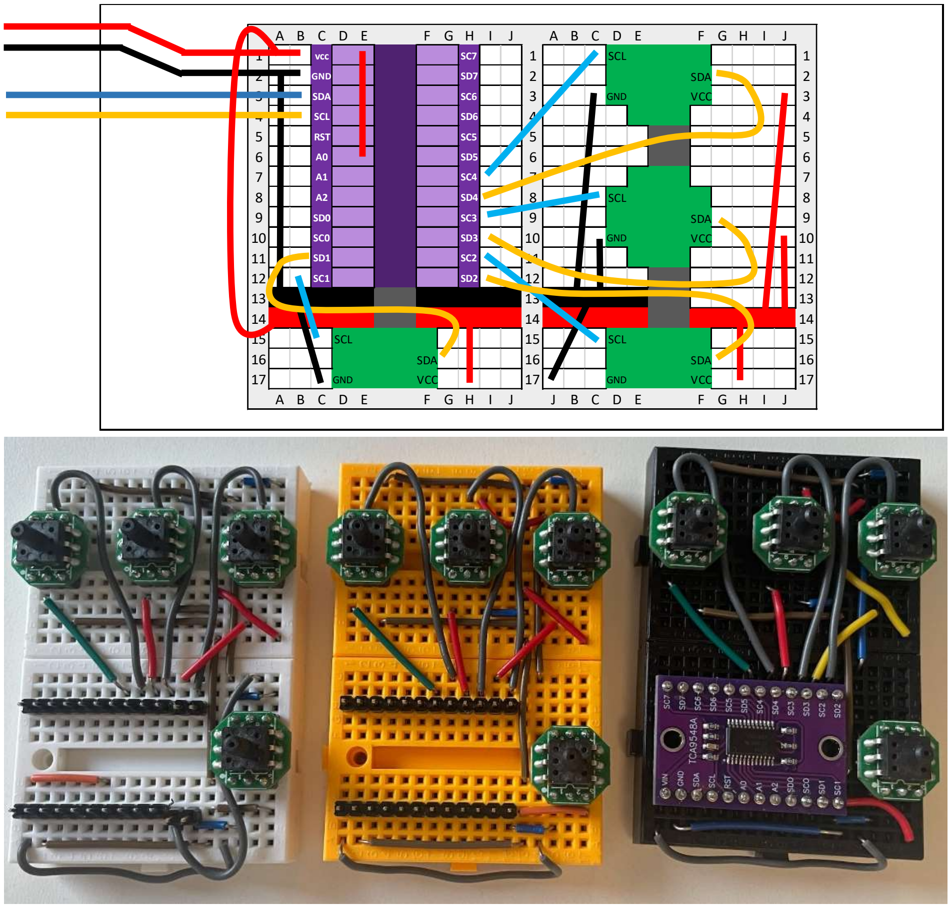


Figure 58 : Sketch and realization of the electronic card

The tip of each captor goes through the lid of the box in little holes and is connected to the hose. It makes it waterproof enough for the experiment:

Figure 59 : Picture of the captors connected to the hydraulic brass fittings

8.13.1.3. Motorized valve

The box can contain two relays controlling each one a motorized valve.

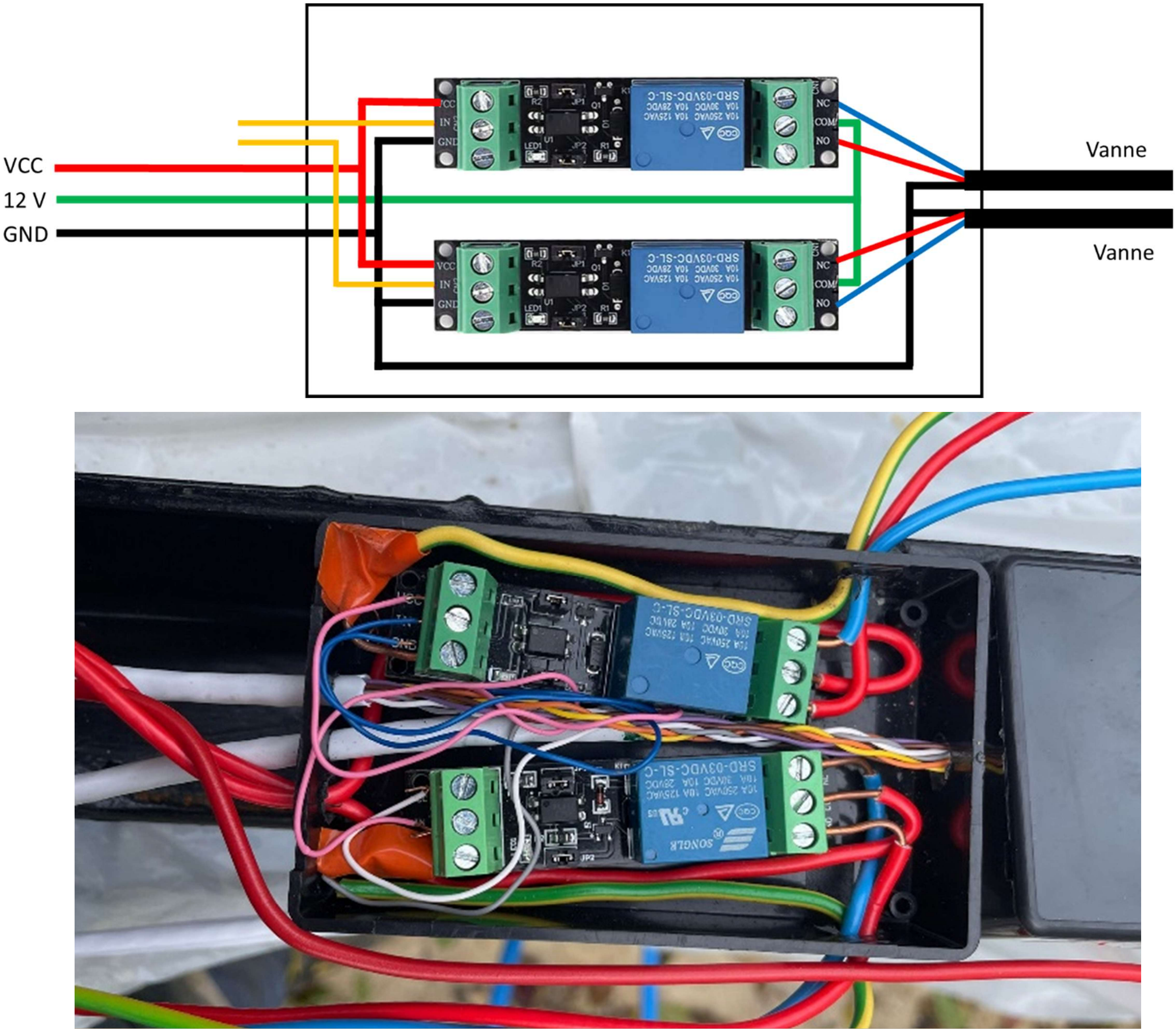
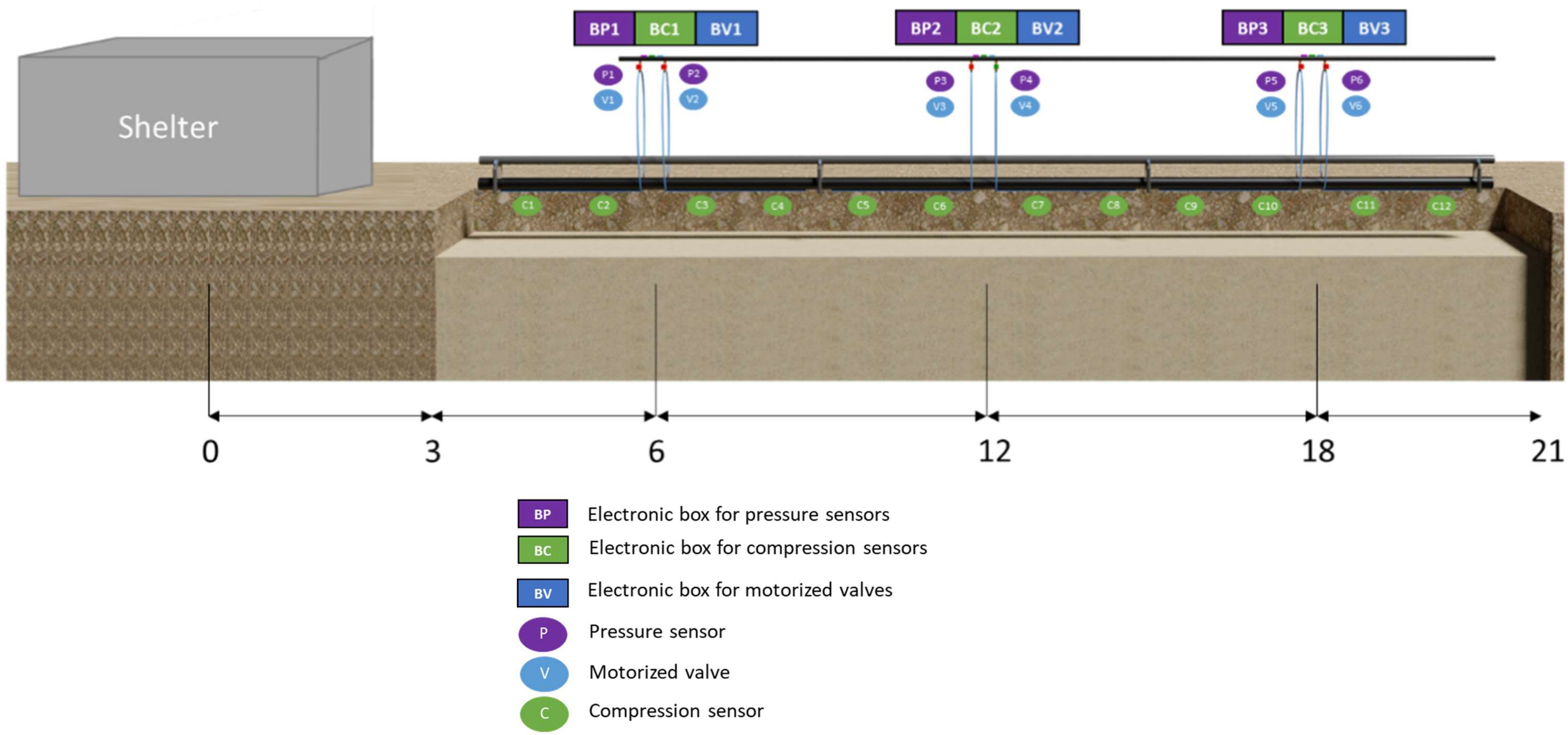


Figure 60 : Sketch and picture of the electronic box for controlling the motorized valves

8.13.1.4. Connections with Arduino card

Everything is about optimizing costs and equipment. The boxes are on the prototype and must be linked to the Arduino card that is connected to my computer. The control / command is done remotely in a shelter. The connection is made by cupper cables grouped together by 8 and are 20 meters for the longest. Each of the 8 cables has a different colored plastic cover. The groups of boxes you see on top are linked together by 3.



Captors and valves are listed in ascending order. C1, C2, C3 and C4 are related to the BC1 box. C5, C6, C7 and C8 to the BC2 box. C9, C10, C11 and C12 to the BC3 box.

8 information cables are necessary for each 3 boxes linked together. It makes one sheath for 3 boxes; it makes it easier for the assembly. The color code I made for the information cables, going back to the Arduino card, to limit the mistakes is as follows:

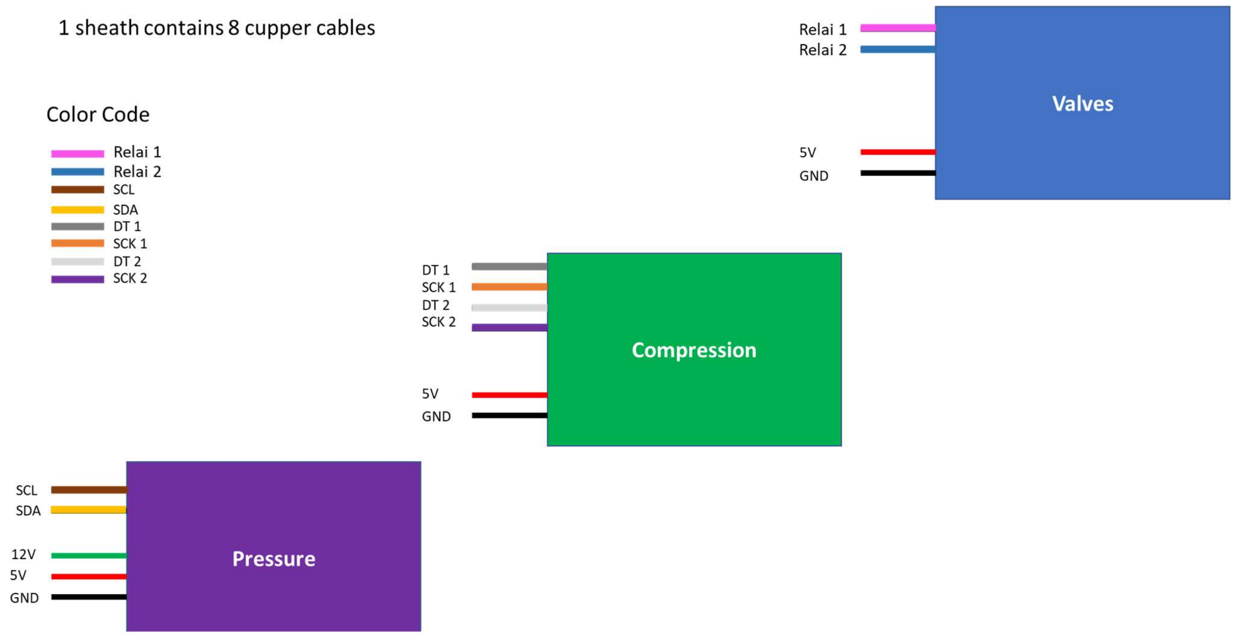


Figure 61 : Color code for the sheaths of 8 cables

SCL/ SDA are the outputs of the multiplexor and are directly linked to the SCL / SDA inputs of the Arduino card. DT, SCK are the outputs of the CAN cards in the compression box, they are linked to the analogic pins of the Arduino card. The two "Relai" are the inputs on the two relays in the valve boxes, they are linked to the digital pins on the Arduino card.

As there are 3 boxes of each type, here is the electric plan of the connections to the Arduino card with the same color code:

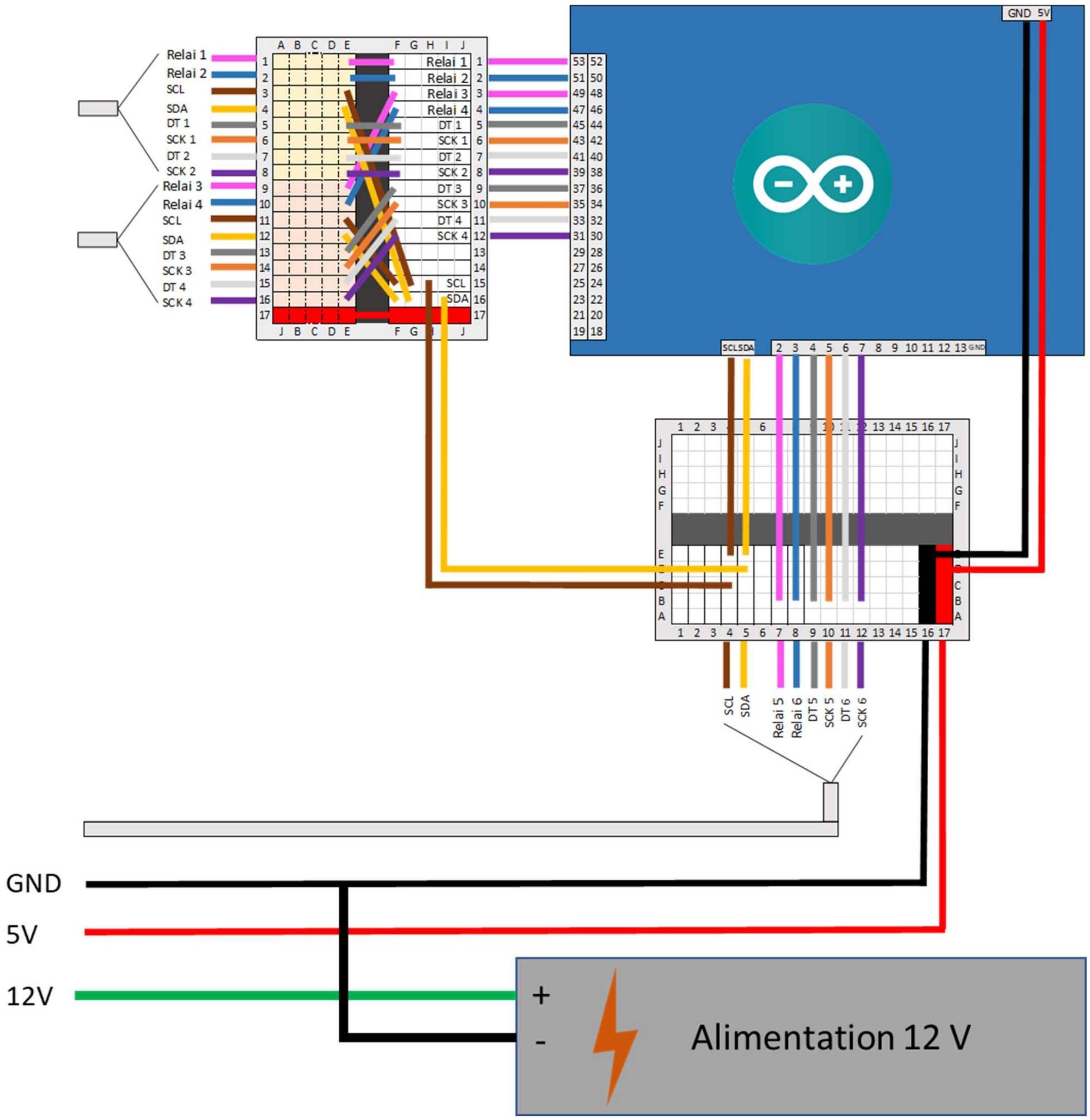
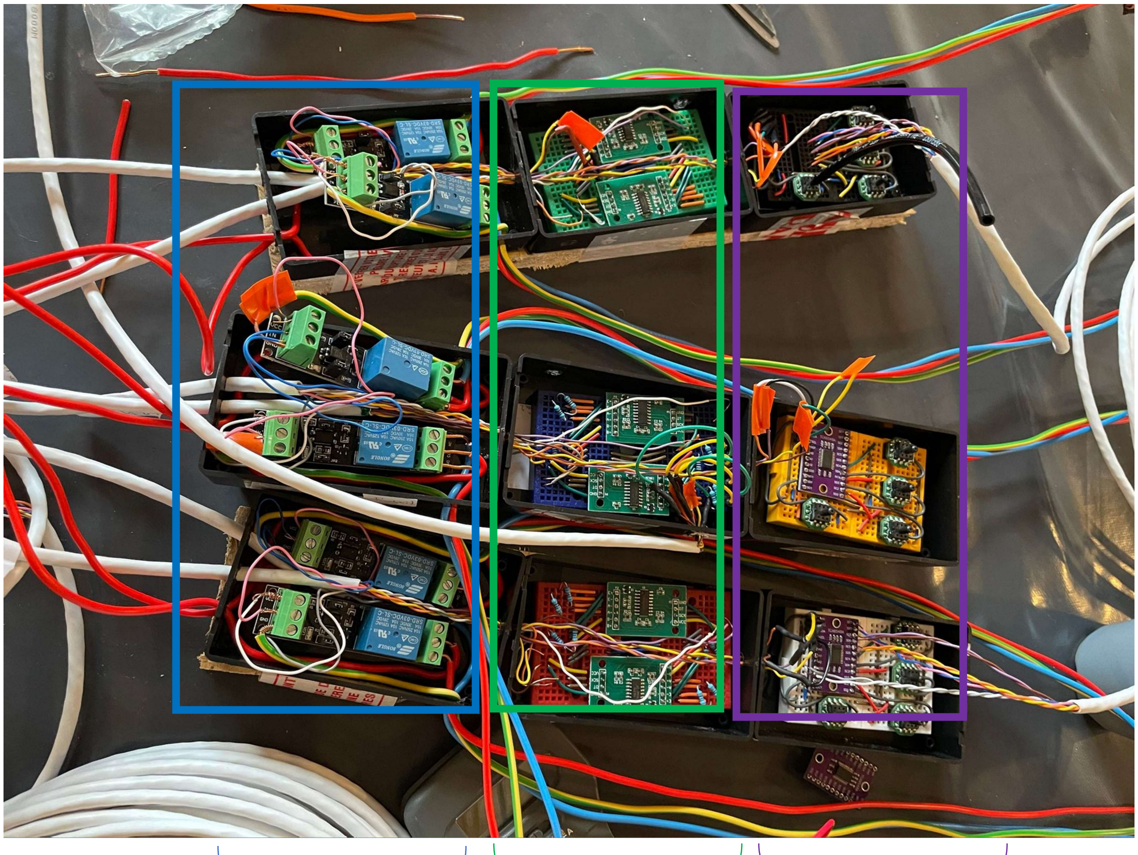


Figure 62 : Electronic diagram of the connections to the Arduino card

Two bread boards and a 12V generator are used.

Here are pictures of the real system. Connecting all those cables was a very long and hard work. It took lots of hours. Many mistakes were made in the connections, I had to test everything to find the errors or the defective equipment.



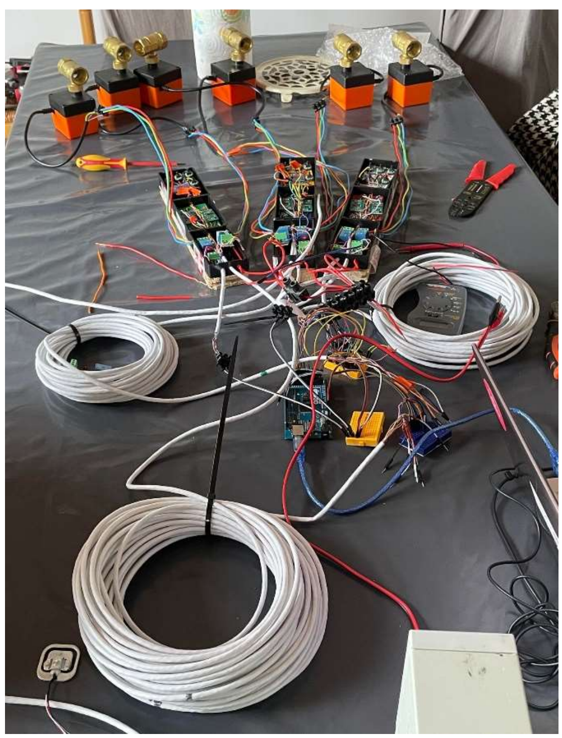


Figure 63 : Pictures of the real system and tests of the valves

Two issues were encountered during that phase:

- First, the limited buffer size of the orders to control the motorized valves. A buffer size of 64 bites is set by default. As a simple command of one valve is 0009-001,00-2-1-1 which is already 17 bites, it is not impossible to deliver a command exceeding 5 valve orders:
  0045-001,00-2-1-1,01-2-1-1,02-2-1-1,03-2-1-1,04-2-1-1

  53 bites

If one more command is added (for the sixth motorized valve) to the actual command, there is automatically an error message. After that, it is not possible to control anything. To modify the buffer size by default (see a tutorial in annexe). You can also find it online here on the web version.

Nevertheless, I realized later that it was impossible to command the six motorized valves at the same time because the VCC and GND pins on the Arduino card cannot support a current superior to 200 mA (in theory). As the current adds up the more you activate motorized valves via the generator, it comes a certain point where the current delivered by the generator is two high and the Arduino card automatically shuts down. According to me, this issue was linked with the fact that the GND of the Arduino card is linked with the 12V generator's.

Thus, in our case, this problem of buffer size is not an issue.

- The second problem was the cable length which, exceeding a certain value, makes the signal distorted so that it cannot be read by the Arduino card. It returns an error message. It took me a while to realize it was the source of the problem. The matter is the cupper cable thickness that is very small. The longest cable (25 meters) long was removed, and the last pressure sensors were connected to the middle multiplexor that had 4 inputs unused, and it worked.

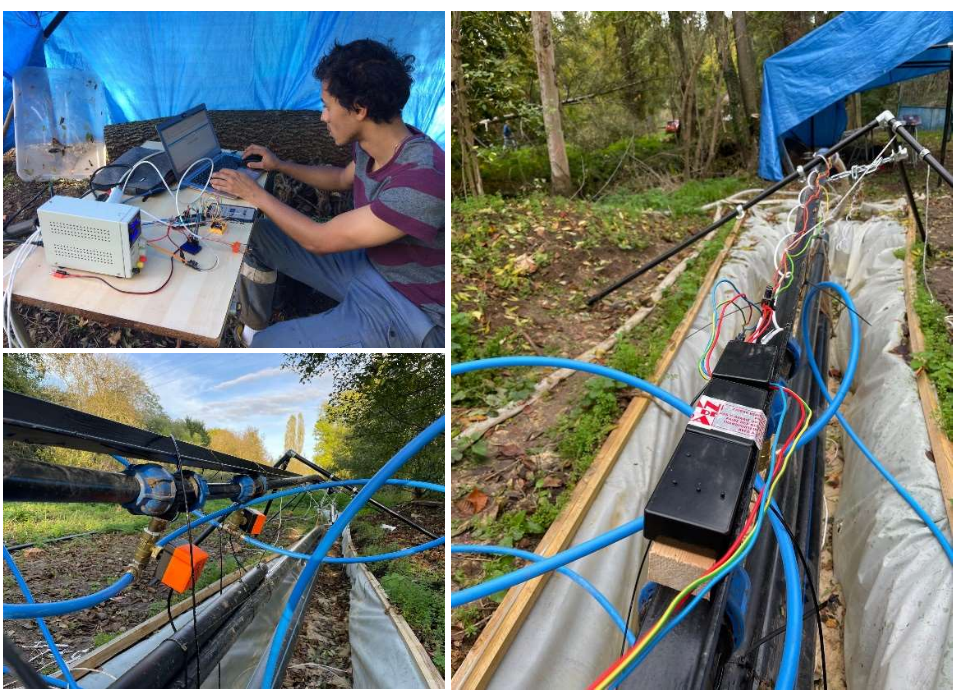
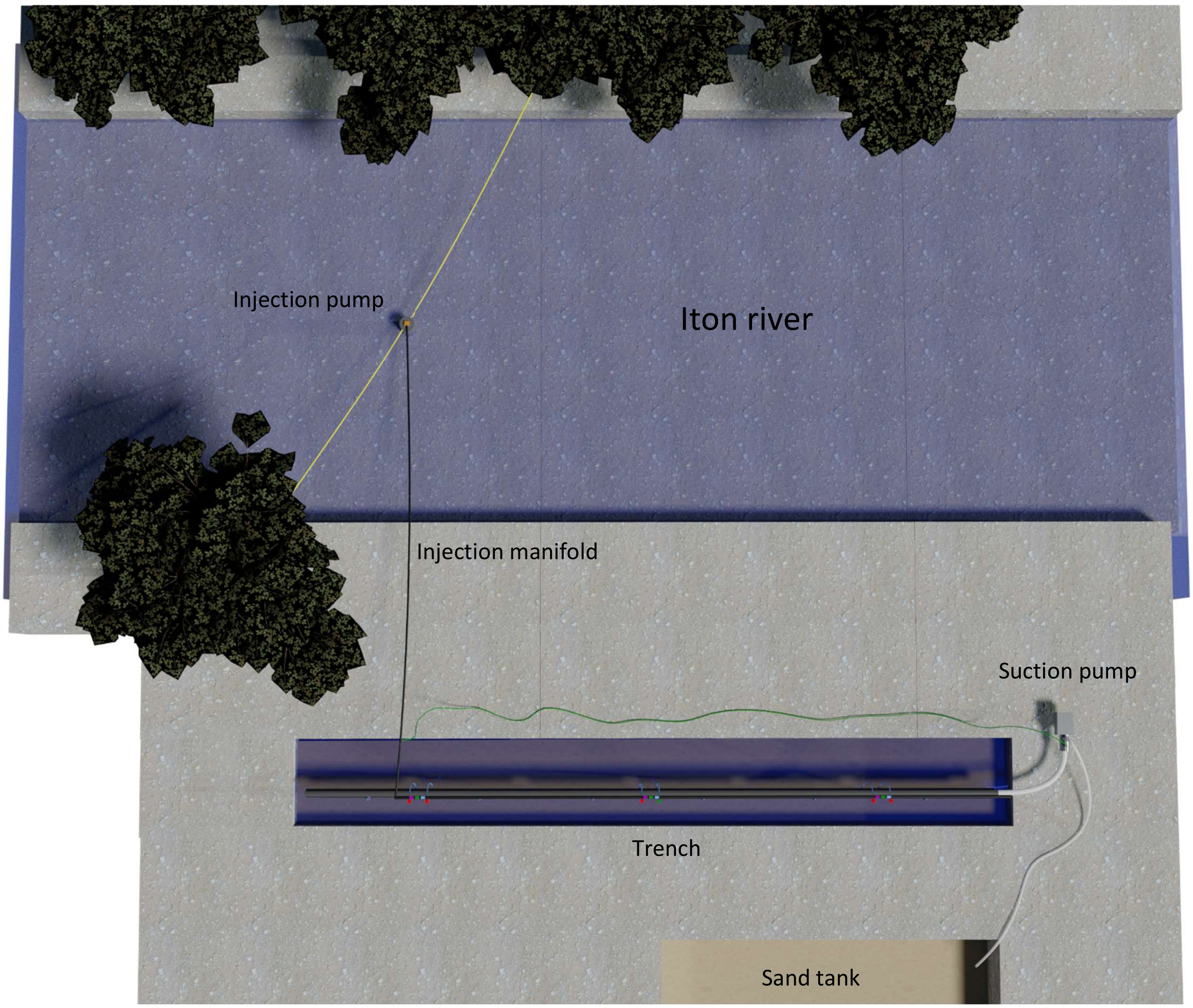
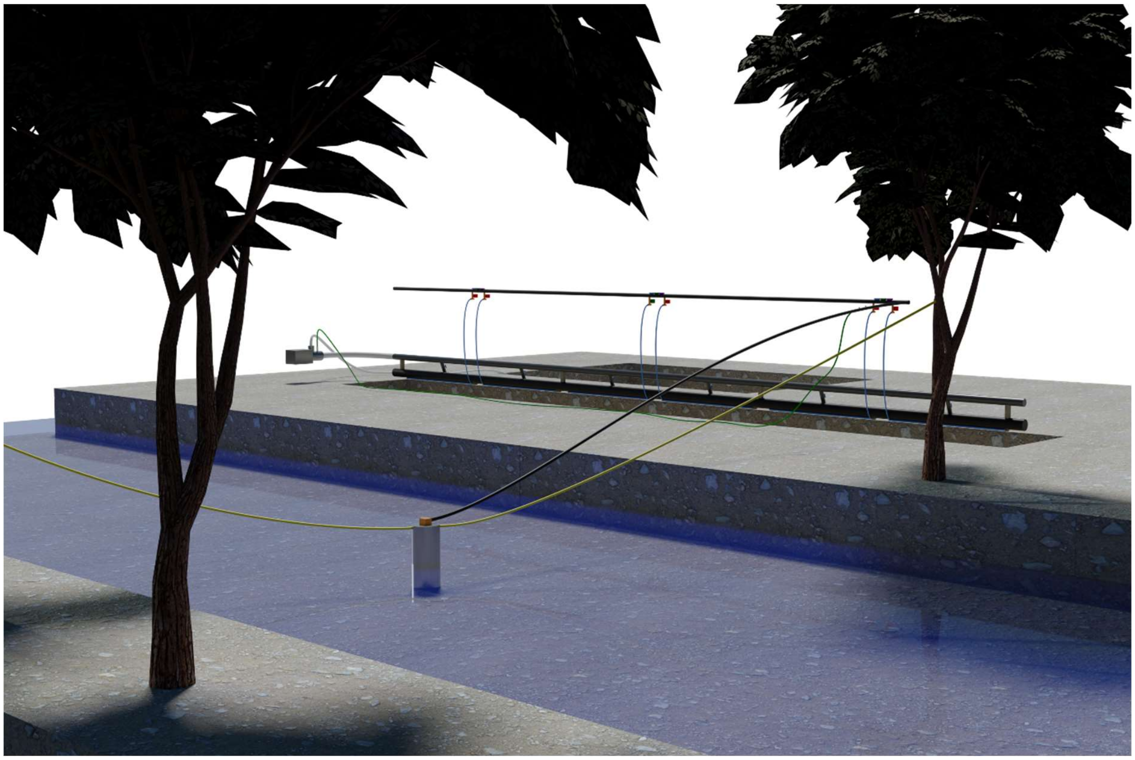
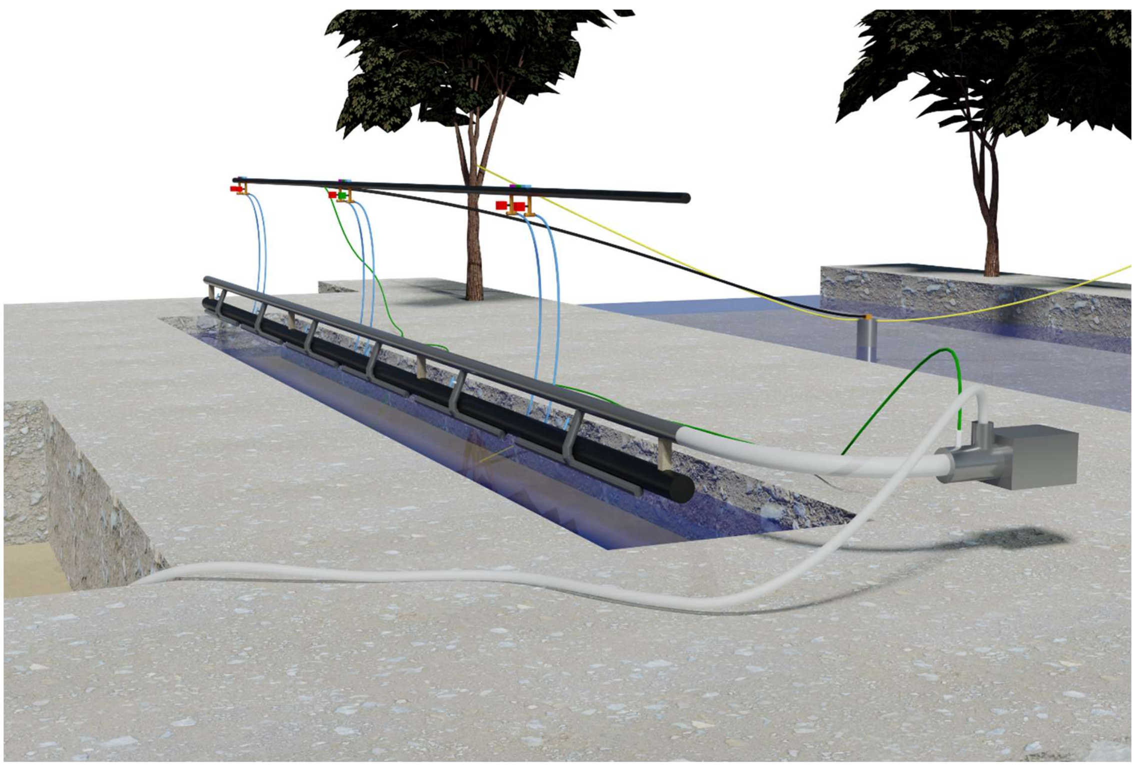


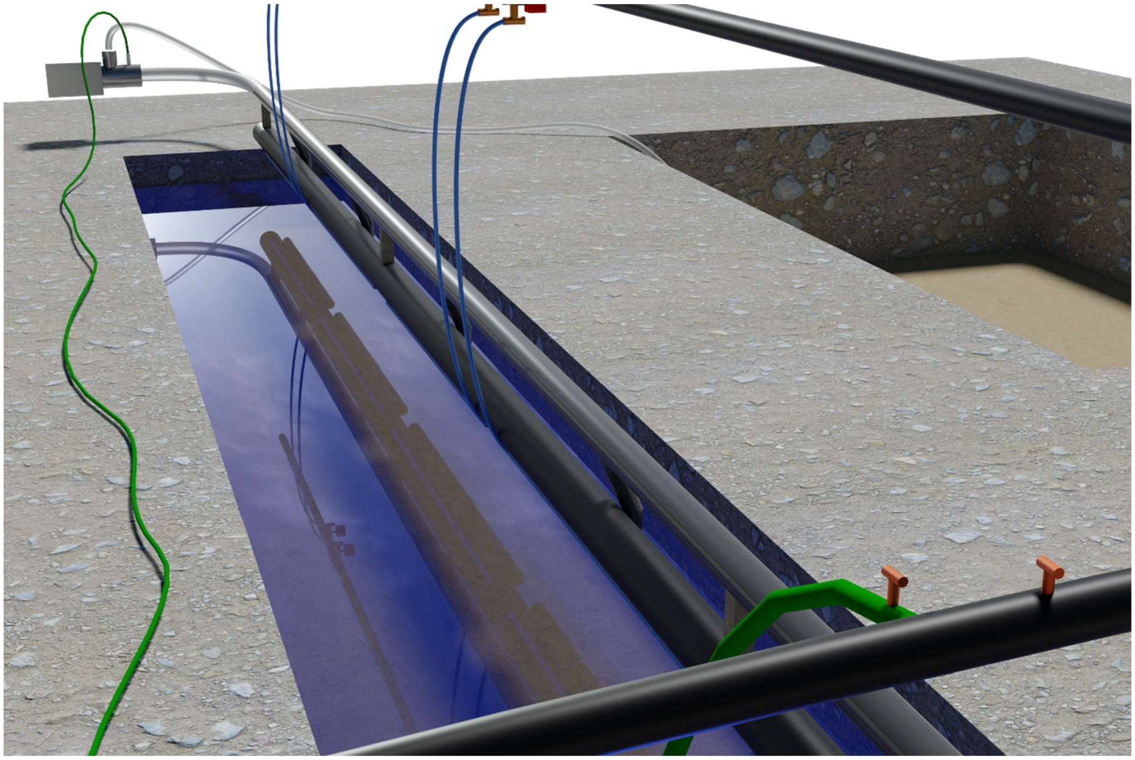
Figure 64 : pictures of the system and me working on it

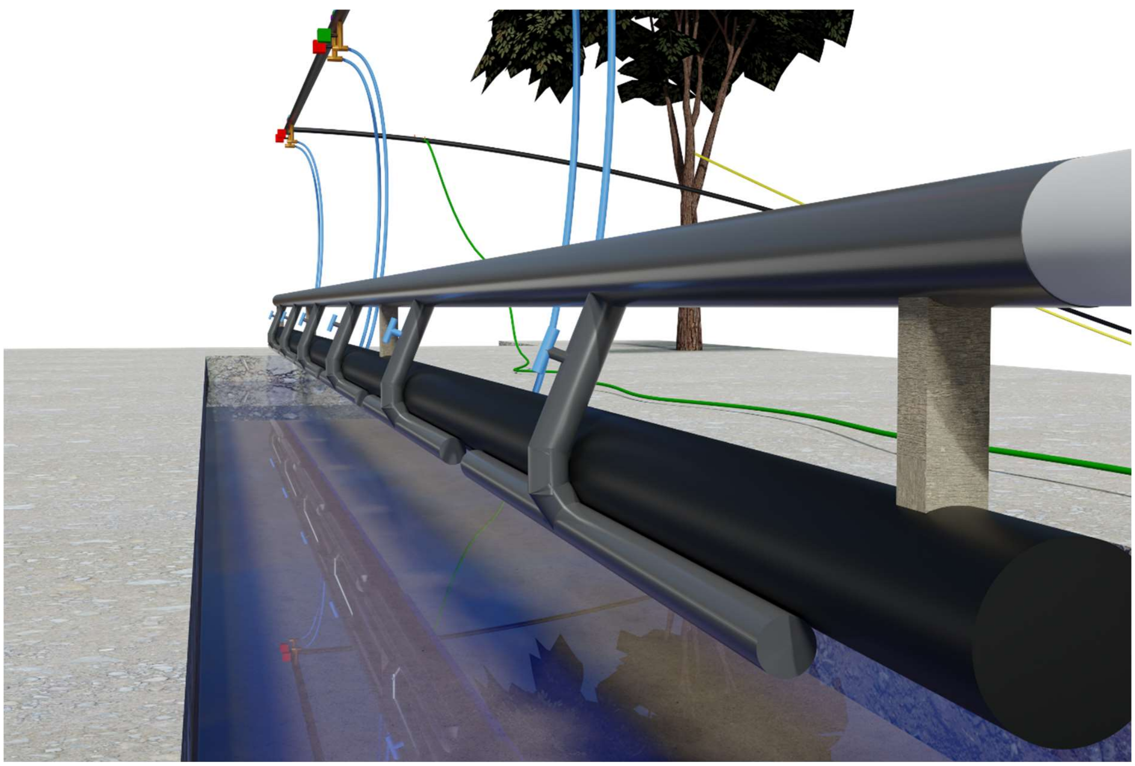
8.14. Simplified view of the site











9. Description of the tests and iterations on the prototype

This section describes the iterations made during the tests. The prototype is made of the 6-m-long sections with injection modules of 3 meter-long. The objective was to bury the whole pipe, but the difficulties encountered during this project led to bury only the first section.

9.1. Two injection modules with jet angles, without the suction system

9.1.1. Design description

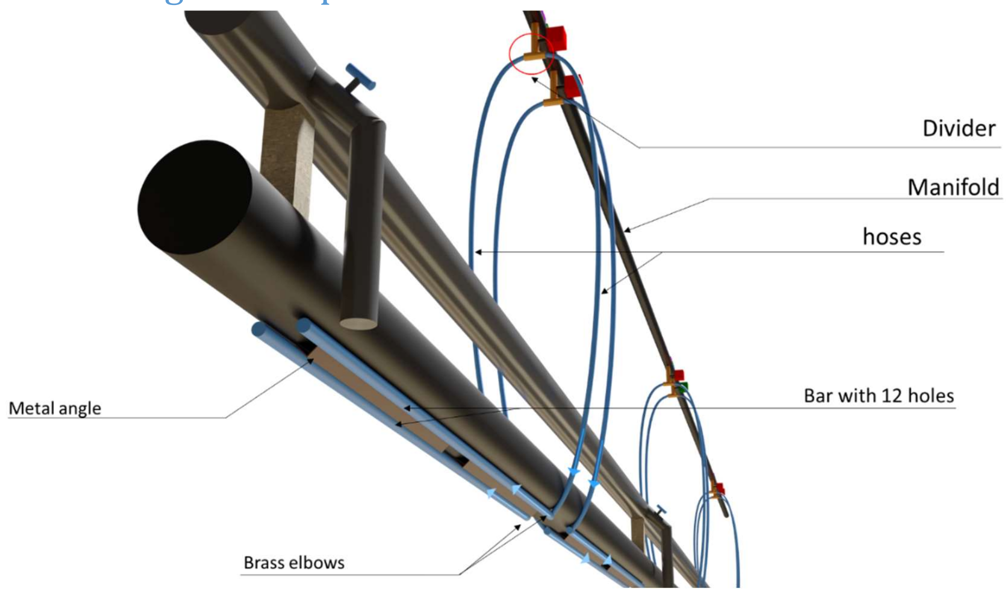


Figure 65 : Diagram of the prototype

The first approach is to test the initial prototype as described in the sixth section. The jets have a particular disposition. On each bar, there are 2 lines of holes. The first line is perpendicular towards the angle's surface (red arrow) and the other one is parallel to it (green arrow).

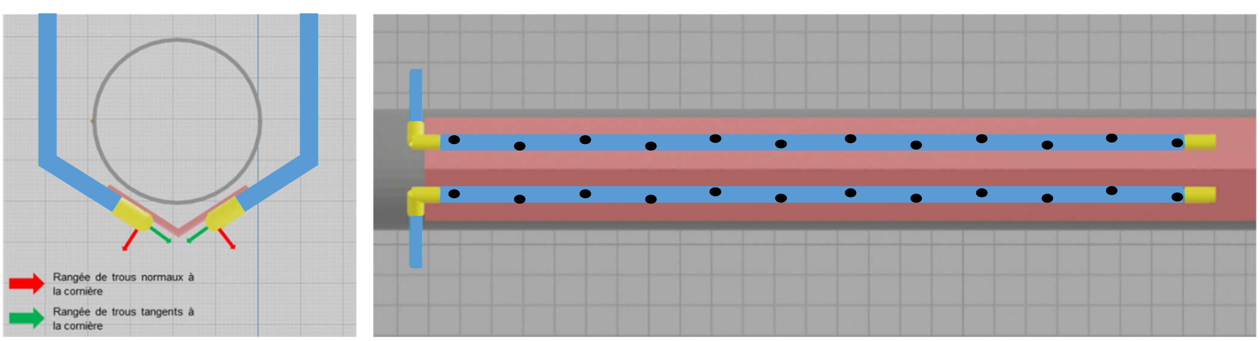


Figure 66: Sectional view and bottom of the injection circuit

The axis of the holes makes an angle of 45°or 135° with the axis of the bar depending on their positions on the bar: Each hole is oriented towards the end of the nearest bar (see *Figure 67)* to direct the flow of fluidized sand towards the nearest suction nozzle(the sandy water suction nozzles being located between each pair of injection modules).

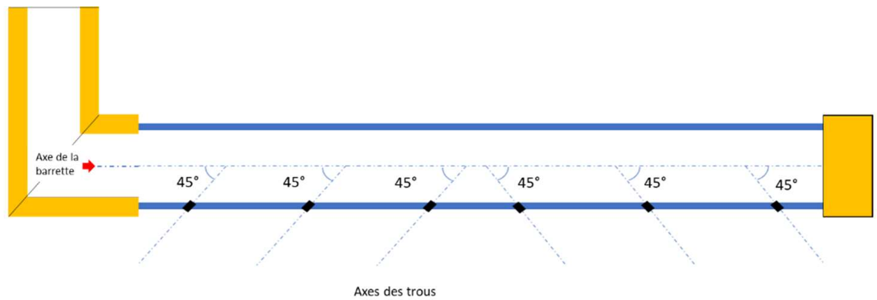


Figure 67 : Diagram showing the directions of the holes drilled in the strip

The holes are arranged so that the jets do not meet.

A hydraulic modeling coupled with experimental tests permitted to determine the best diameter of holes to maximize the power of water jets: 2 mm. This result will be questioned during the experimentation phase.

9.1.2. Tests results

The first tests we made were on the sand without water (dry sand) and then in the water without the suction system. The results were similar:

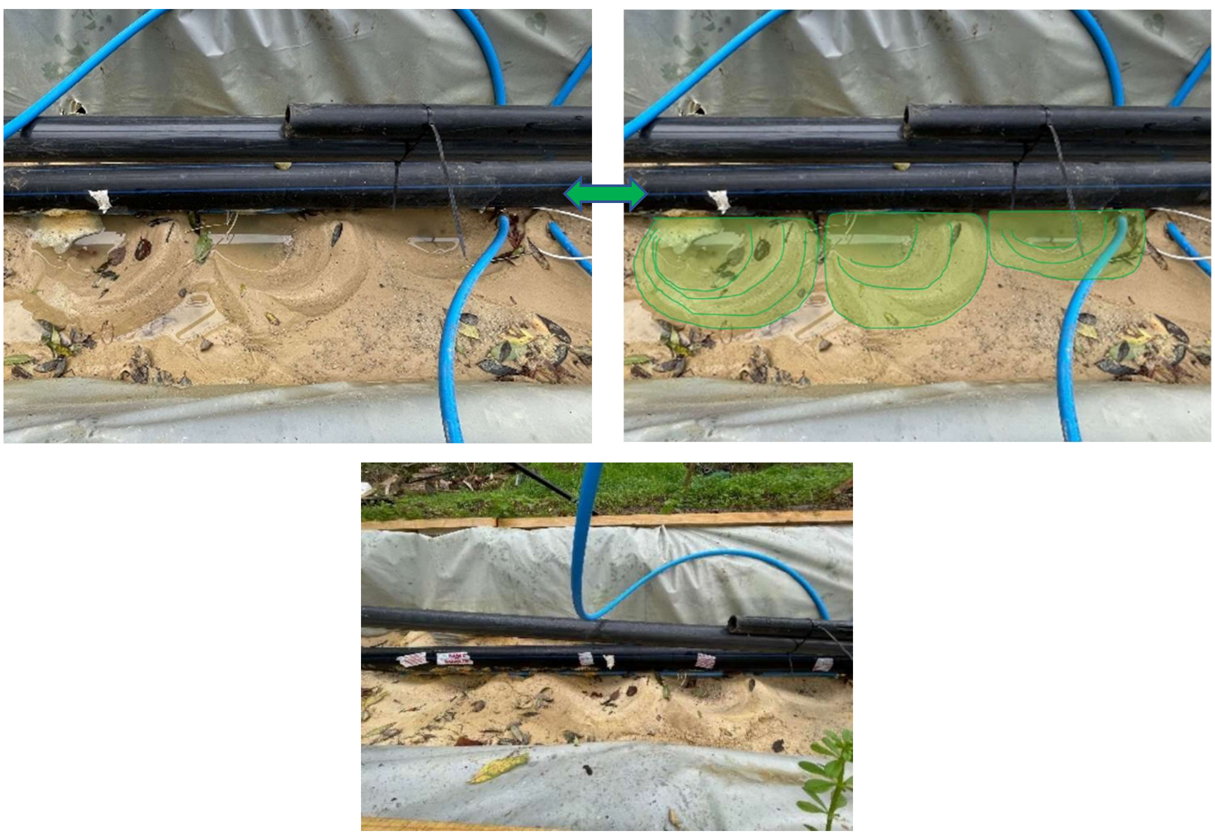


Figure 68 : First results

- The water jets are very powerful: They penetrate over 20 cm through the sand.

- The problem is their orientation that is clearly not the efficient one: You can easily distinguish those large pools drown on the sand. the water jets directed outwards liquefy the sand and push it outside. However, it does it only alongside the jet and it is not efficient to push the sand located between the jets away.

Thus, a large amount of sand persists between the trails, and it blocks the pipe burying.

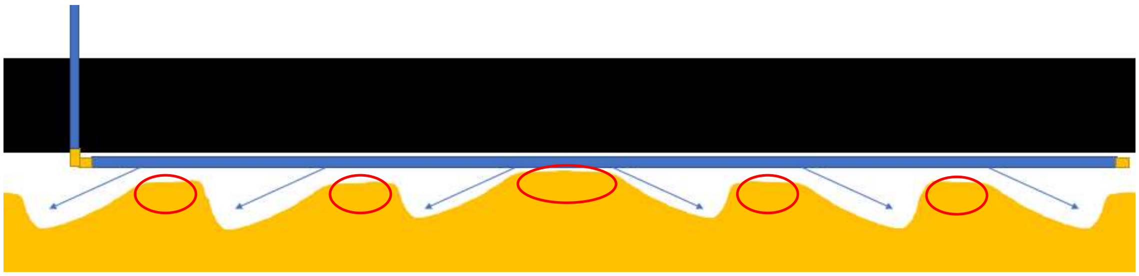


Figure 69 : Side view

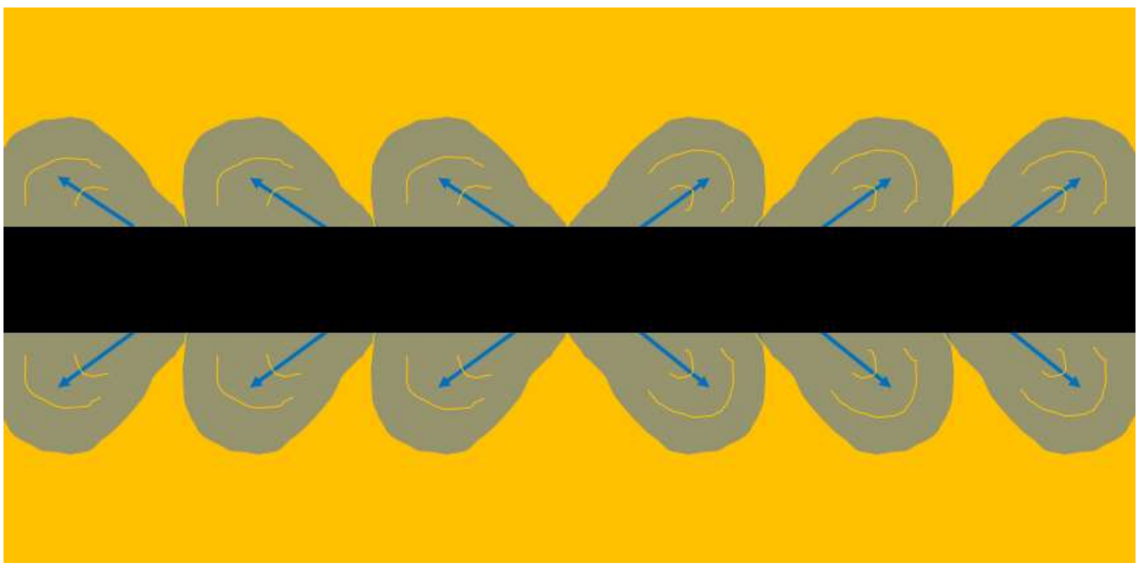


Figure 70 : Top view

9.2. 2 Injection modules with jets directed downwards

After several tests, the jets orientation was modified to be always downwards so that the jets' power is fully directed to the sand.

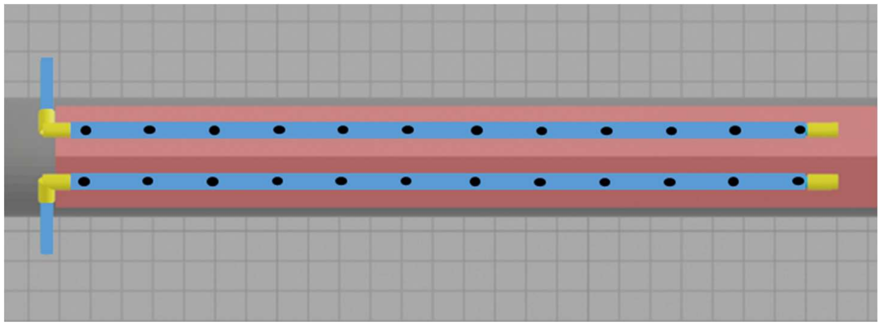


Figure 71 : Bottom view

The pictures show the improvement:

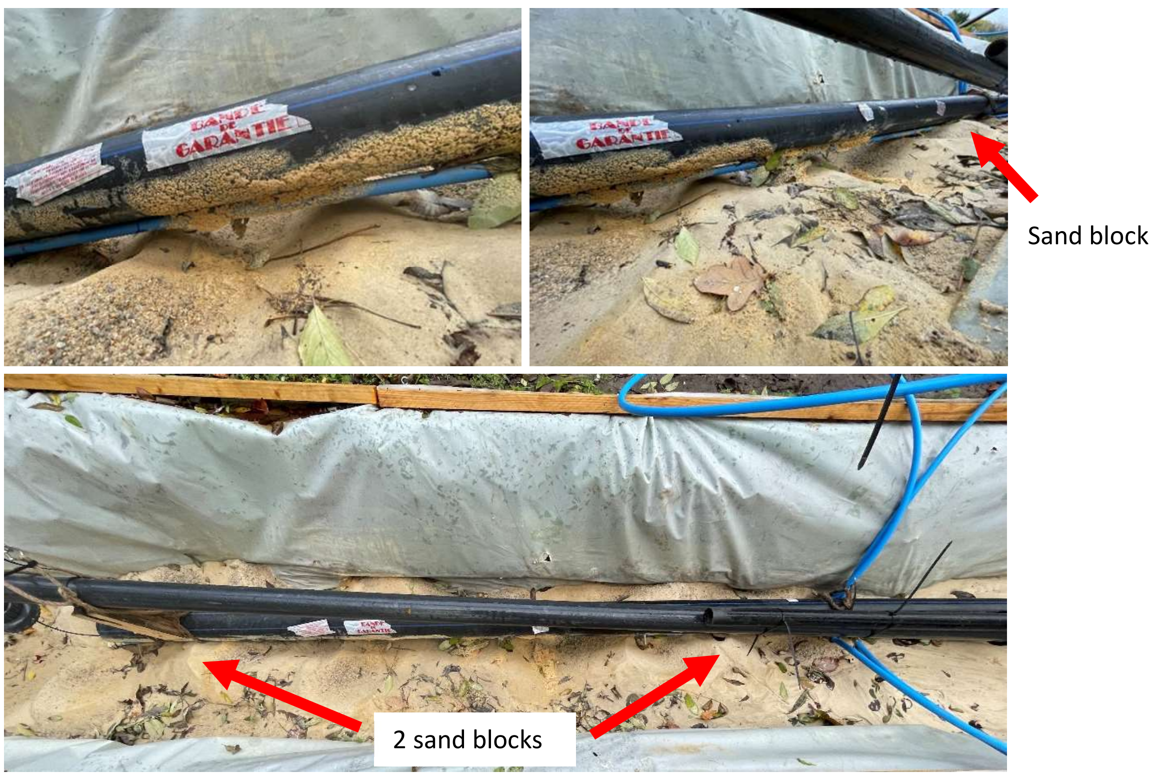


Figure 72 : Tests results

The trails are smaller, less visible, and more disordered. That is a step forward since the disorder generated is greater and oriented below the SWAC tube. Secondly, the blocks that previously obstructed the burying are smaller so that the SWAC tube stands in very few sand supports.

The result could be improved by doubling the jets number. If the number of jets was doubled, the last blocks of sand would certainly be destroyed. However, doubling the jets would need to double the flow rate and adding another pump in parallel, which could have been feasible. However, at this step, it was supposed that adding the suction circuit could solve the problem without adding the other pump.

9.3. Injection modules and suction circuit with single nozzle

This test is based on the hypothesis that the suction nozzle will induce a current in liquefied sand and will little by little shatter the sand blocks on the whole section of the jet injection.

The following sketches show the expected principle of the suction:

- The red and blue arrows represent the injectors and the pale yellow around shows the liquefied sand. Each injector creates a "pool" of liquefied sand, each one separated from one another by a sand block (dark yellow)
- The current created by the suction is expected to break the sand blocks and liquefy the sand from one to the next and thus liquefy all the sand below the pipe section.

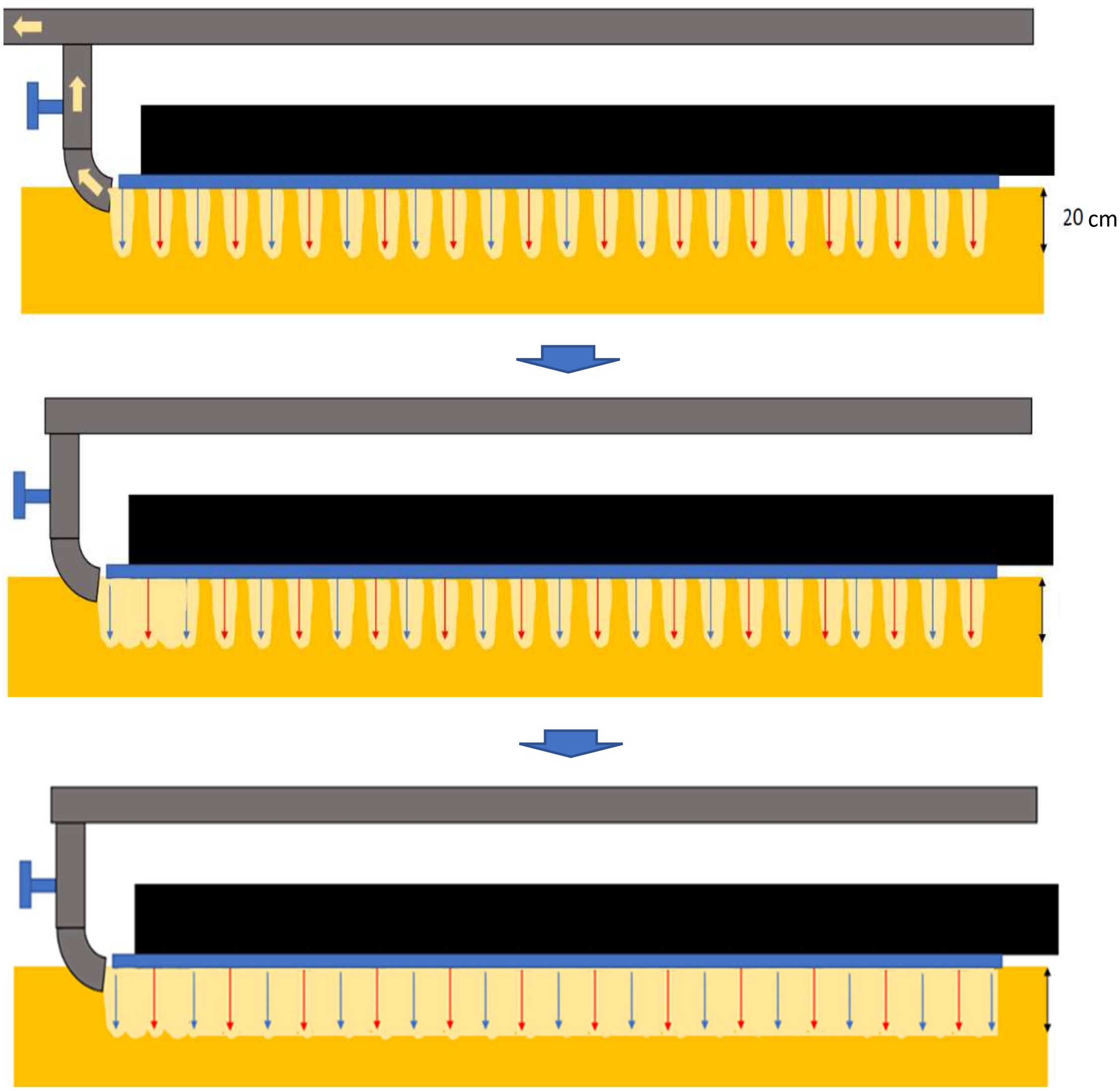


Figure 73 : Suction principle

The hypothesis is verified on the first meter. The tip of the tube went down rapidly by approximately 5 cm (half the pipe diameter). However, fate one meter, sand blocks remain in place and prevent the burying.

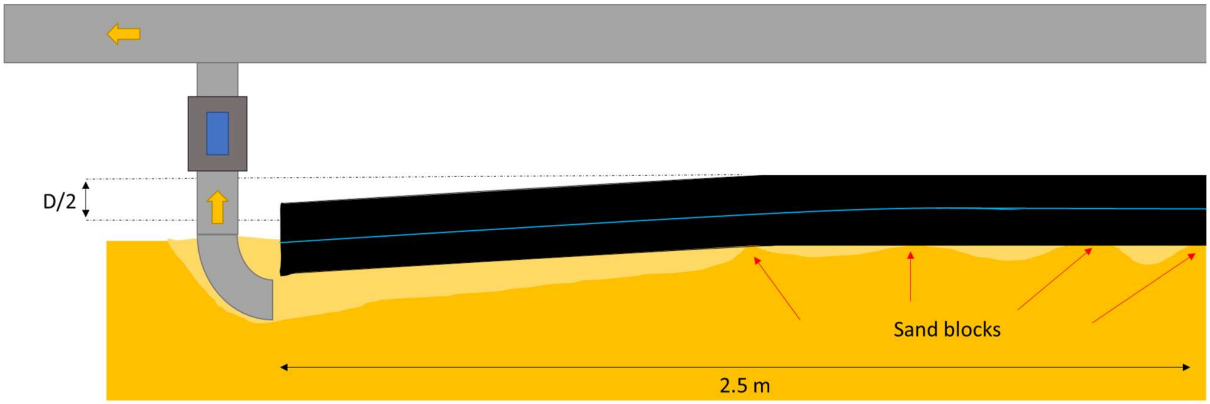


Figure 75 : Diagram of the half-silted tube's tip

Figure 75 : Explicit results

There are many explanations for that:

- The pipe's flexibility is limited. The quick study part 6 shows that for a 6 meters long HDPE tube blocked at both ends, the maximum flexion will be less than 2 diameters. But, this is not enough to explain the result.
- The sandy water suction is not powerful enough to generate a current exceeding one meter.

It is possible to measure the silting in real-time using the ropes used to lift the prototype. It is sufficient to put a marker on it and to stretch the rope.

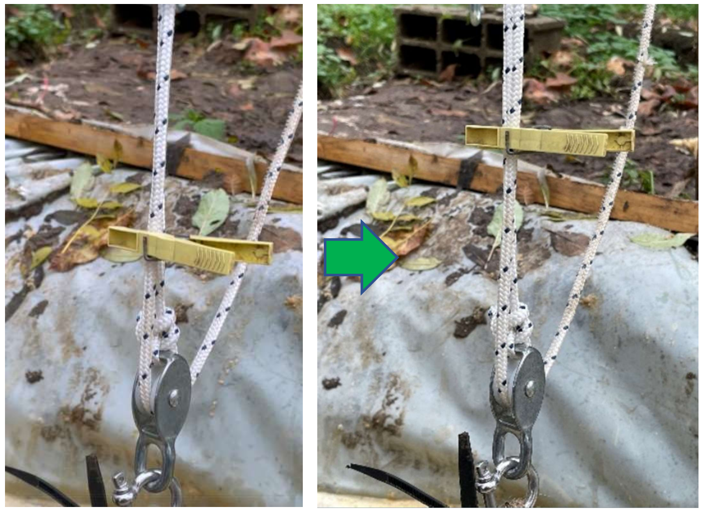


Figure 76 : Silting process

9.4. Single injection bar and suction circuit with 12 nozzles

Regarding the problem of using a single nozzle for suction, it seems clear that to expand the performances of the suction on the total slice of 3 meters, the single suction nozzle must be divided in smaller nozzles and distributed on the total length. The whole nozzle's section was divided in 13 pieces with an increasing section as it moves away from the valve:

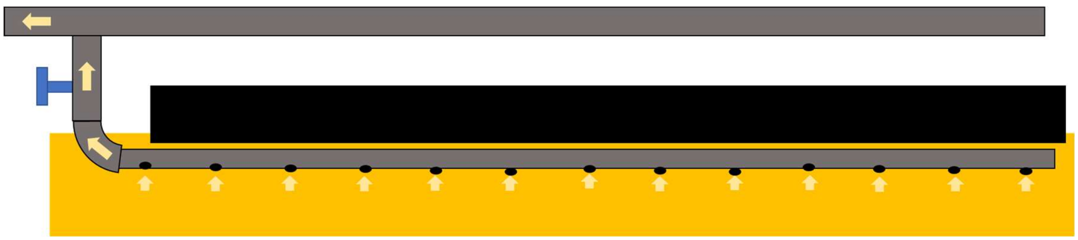


Figure 77 : Diagram of the new suction system

Thus, as the suction nozzles are in front of the water jets, the sand in suspension will go directly in the nozzle.

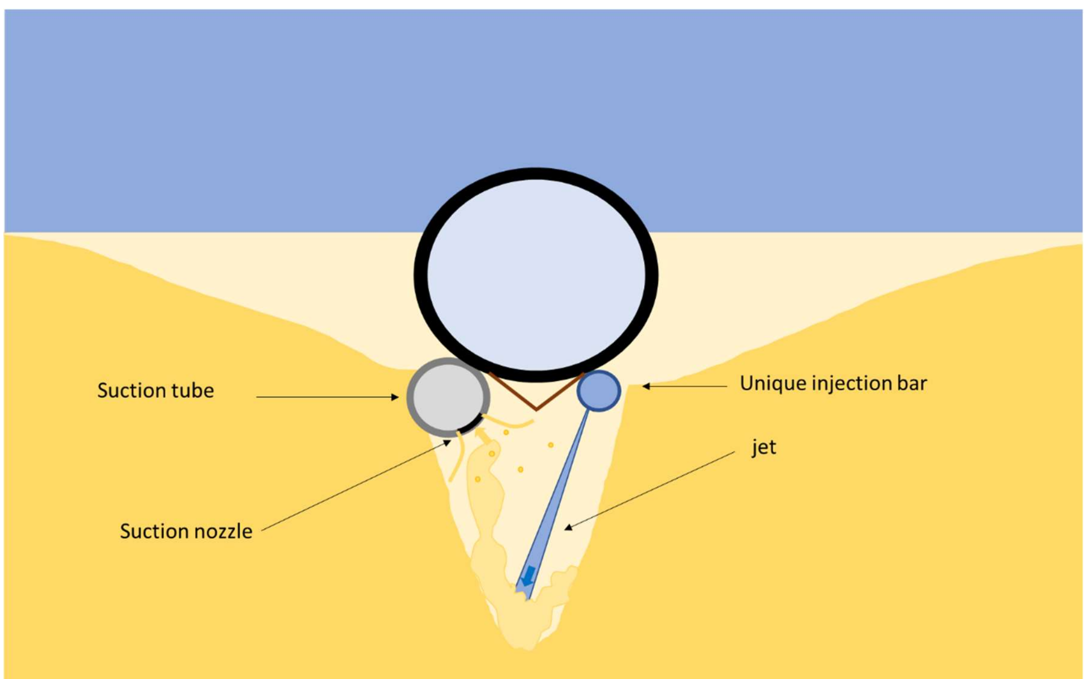


Figure 78 : Diagram of the concept principle

The first observation was that sand blocks are fewer. It means that the couple injection / suction works well. The suspended sand does not redeposit at the same place, and is removed from the trench by the suction nozzles. It was visible by the large amount of sand that was circulating in the translucent pipes.

Sand blocks still prevent the pipe from burying. The result is worse than a single nozzle suction for two reasons:

- With the suction collector connected at the extremity of the bar, head losses in the end are high. Thus, the suction in the last nozzles is almost zero. But this is not enough to explain the result.
- It was observed that nozzles were blocked by leafs and brushwoods. Therefore, the holes section was increased to improve the performances.

Figure 79 : Pictures of the results

9.5. middle suction pipe

To reduce the head losses in the suction bar, the suction pipe is moved in the middle. It will also allow to drill bigger holes on it. For that we needed to drill a hole on the manifold, to glue fittings and add another valve.

We had a lot of trouble doing it work as the quantity of sand sucked was greater. The amount of sand was so large that it generally clogged the pipe, shutting down the suction system.

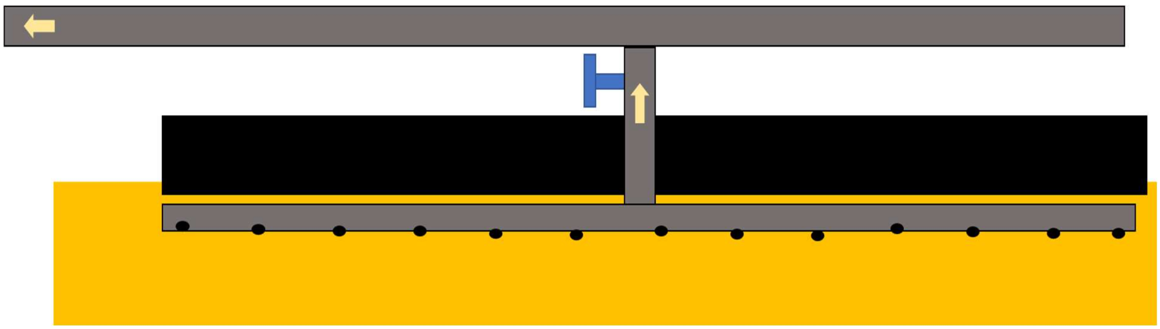


Figure 81 : Diagram of the new suction system

Figure 80 : Results

Finally, the test was successful as the whole system dived into the trench. However, it seems that the pipe slided down slowly by the sandy slope the couple injection/ suction made.

It was a predictable issue regarding the system's shape which is not symmetrical at all. Indeed, suction bar's diameter is pretty much larger than the injection bars. It makes the whole system unstable as it lies only on the suction bar.

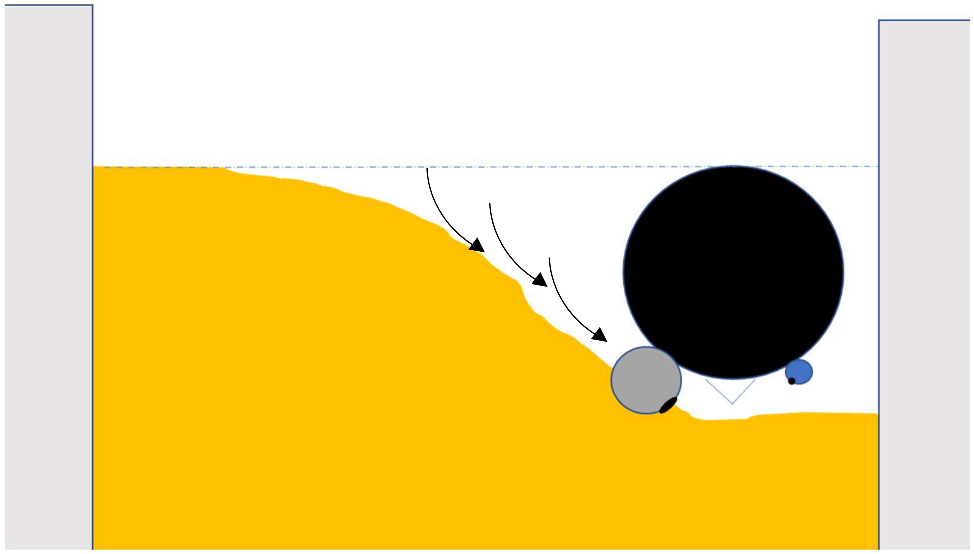


Figure 82 : Diagram illustrating the results

The performances of silting are better, but the same problems persist as before such as the sand blocks and few clogs.

To go further, to improve the system, we needed to understand exactly the process of injection / aspiration. Nevertheless, the opaque water prevents to see anything.

9.6. The aquarium and pressurized air

Due to the opaque water, it is not possible to observe anything underwater during the tests. To solve the last problems that block the sinking (sand deposits, blocked holes, and clogs), the solution considered is to use an aquarium of 1 m long, with a transparent bottom glass, which will replace the SWAC tube to allow the visualization of the sinking in the trench.

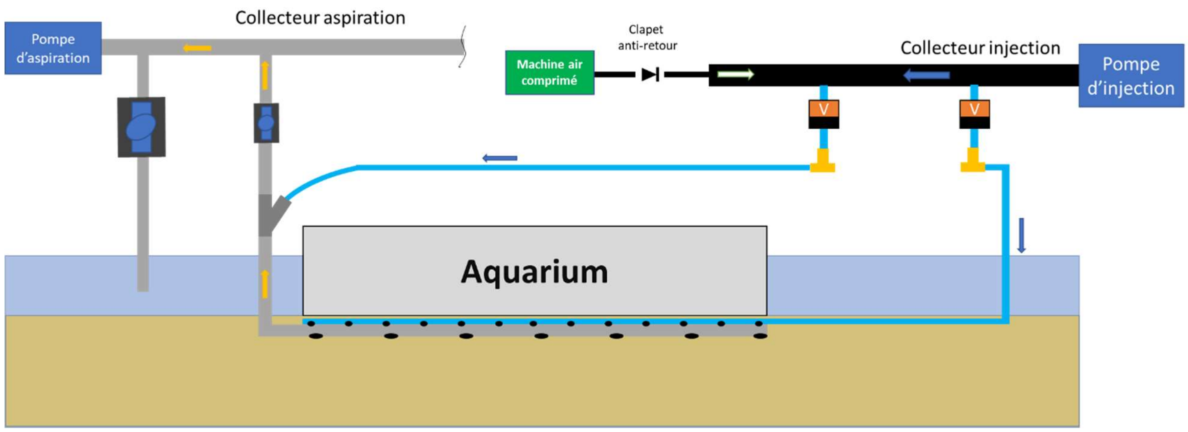


Figure 83 : Diagram of the aquarium set up

The aquarium dimensions are 1m x 0.35m x 0.45m. The injection circuit is drilled every 20 cm. The number of holes will be doubled (i.e., then every 10 cm). The suction circuit is drilled every 15cm.

The injection circuit is connected with a motorized valve to the suction circuit to inject water via the suction holes. The aim is to desilt the suction holes if necessary.

The pressurized air system was added during that phase. It allowed us to test it with more visible results to conclude on its usefulness or not.

Note: To avoid sucking air, the suction system cannot be turned on during the injection of compressed air.

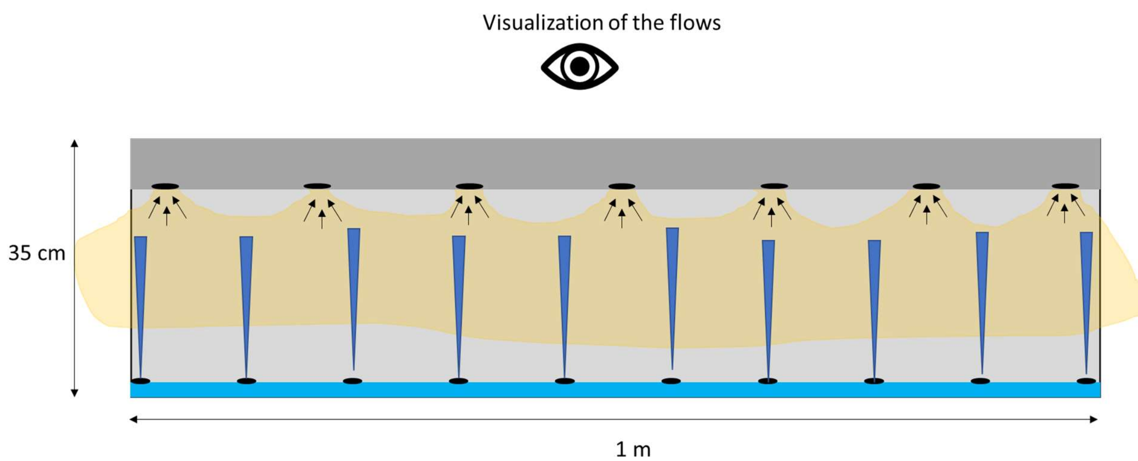


Figure 84 : Top view of the aquarium

The aquarium is empty (full of air) during the test. It is a constraint as it is halfway submerged, the water pressure on its vertical/bottom surfaces is high. To prevent the aquarium from floating, we added two metal-made armatures to ballast it enough. One outside and one inside the aquarium.

Figure 85 : Phots of the metal made armatures

The tests with injection holes every 15cm made those characteristic sand trails:

Figure 86 : Characteristic sand trails

Figure 87 : Illustration of the results for jets every 20 cm

That is typically what we do not want. In fact, those trails are like sand blocks. It is the sign that the jets are not close enough, as powerful they are. To generate the maximum disorder, it is necessary to bring them closer. The number of holes was doubled, and the experience was tested again.

The most interesting results were here:

Figure 88 : Jets ignition

The jets ignition takes 5 seconds, the necessary time to evacuate the trapped air of the pipes.

Figure 89 : Phase 1: jets going to their maximum range

Lets distinguish two phases. The first one on the images above is the laps where jets try to reach their maximum range. You can notice that their thickness is reduced. An explaination can be formulated : every jet is, at this moment, trapped between two sand trails as before. They have no other choice to continue in their easiest direction. Each one of them creates a little convection circuit that goes back to the opposite direction :

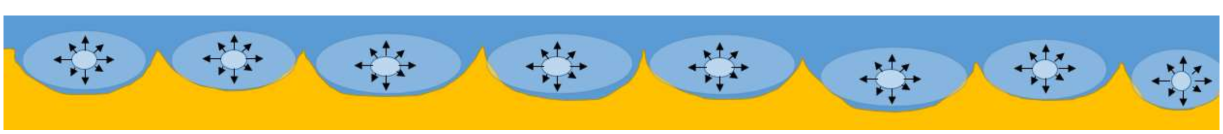


Figure 90 : Phase 1: Thin convection circuits. Front view

As the jets are very close, the sand blocks are very thin and easy to break.

Figure 91 : Phase 2 : Chaos

Once the sand blocks are destroyed by the water jets, "chaos" can begin. It can be seen that larger convection circuits were formed by jets associations. Current can easily blow static sand particules and make maximum desorder that is sucked out by the suction nozzles.

The result was a complete disordered plan.

9.6.1.1. Analysis

It is now necessary to put into perspective those observations with the real system : the self-burying prototype.

For this experiment, as we needed to see clearly the cinematic behavior of the water jets and sand particules movments, we placed the jets horizontaly. In reality, they are vertical. Nevertheless, the

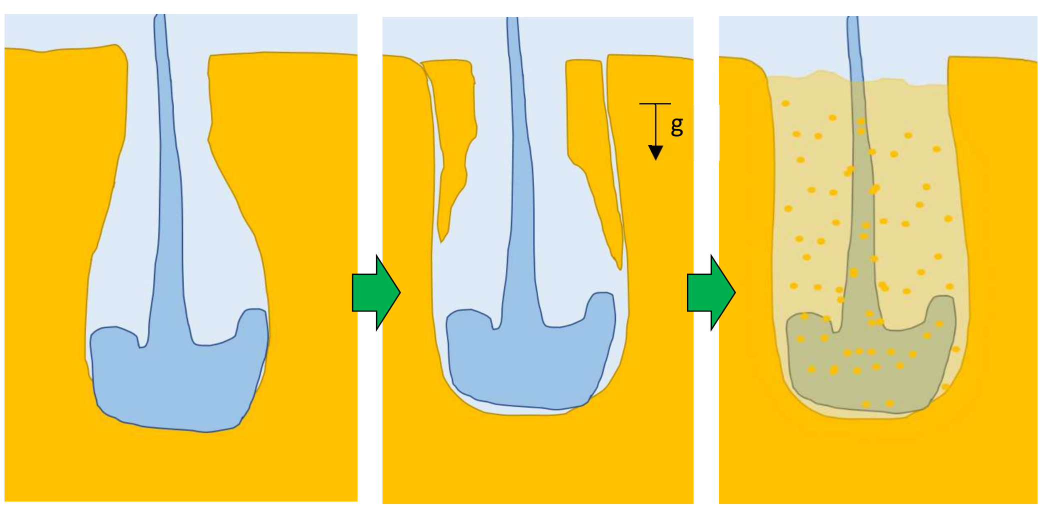


Figure 92 : Sand blocks fall

sand behevior is similar with the exception that the sand blocks fall verticaly in the holes dug by the jets :

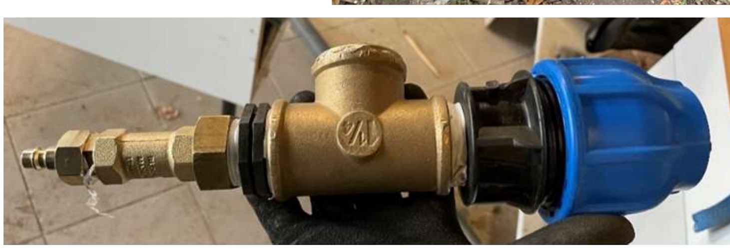
Then if the jets are close enough, they will blow the last sand blocks that previously prevented the prototype from sinking. One part of the suspended sand is sucked out by the suction circuit, the other part falls back into the trench or outside. The major point is that the sand level below the prototype lowers significantly.

In conclusion, this test allowed us to realize that the jets needed to be closer to have a significant and global impact on the whole surface below the prototype.

9.6.1.2. Pressurized air system

As illustrated on the sketches of the global system, the pressurized air machine is connected at the end of the manifold.

Pressurized air machine



Machine / manifold fitting

Figure 93 : Pictures of the machine and the fitting

The pressurized air injection has only been tested with the aquarium. The result is satisfying as it generated disorder on the sand bed. However, some of the ejected air entered in the suction system by the suction bar and defused the suction pump. Thus, it cannot be used while the suction is on.

9.7. Injection nozzles diameter

During the experimentations, it has been faced out that many injection nozzles were partially blocked. The pressurized water coming out of these nozzles lost half of their power. This problem is due to drilling defects. During the drilling, the PER material laminates locally and creates small chips that stay blocked in the nozzle. It has been settled that in order to prevent from this problem, the diameter of the nozzles, initially fixed to 2mm, has been increased to 3 mm.

9.8. End of 2022 test campaign

In December 2022, the cold weather made tests impossible (water freezing in the circuits), and it was decided to stop the test campaign until next spring.

9.9. March 2023 test campaign

In March 2023, a 2 weeks tests campaign was performed (13-24 Mars 2023). The objective was to burry the whole pipe.

9.9.1. Activities performed

The following activities were performed:

- Reinstall the prototype in the trench and pumping system in the river (see Figure 94 and Figure 96)
- Motor oil change
- Modify the prototype as follows:
    - Equip the remaining sections of the SWAC tube with injection modules as per 2022 optimization (note that only 5 sections have been equipped: the sixth section was not equipped – see Figure 97
    - Equip the remaining sections of the SWAC tube with sandy water aspiration as per 2022 optimization (note that only 5 sections have been equipped: the sixth section was not equipped) – see Figure 97
    - Correct the leaks on the compressed air injection circuit
    - Add a second pump on the aspiration circuit (Figure 95)

The equipment of the remaining sections of the SWAC tube with injection and aspiration modules was time consuming as well as leaks plugging.

Figure 94: March 2023 - prototype in the trench

Figure 95: March 2023 - 2 pumps installed in the river

Figure 96: March 2023 - prototype in the trench

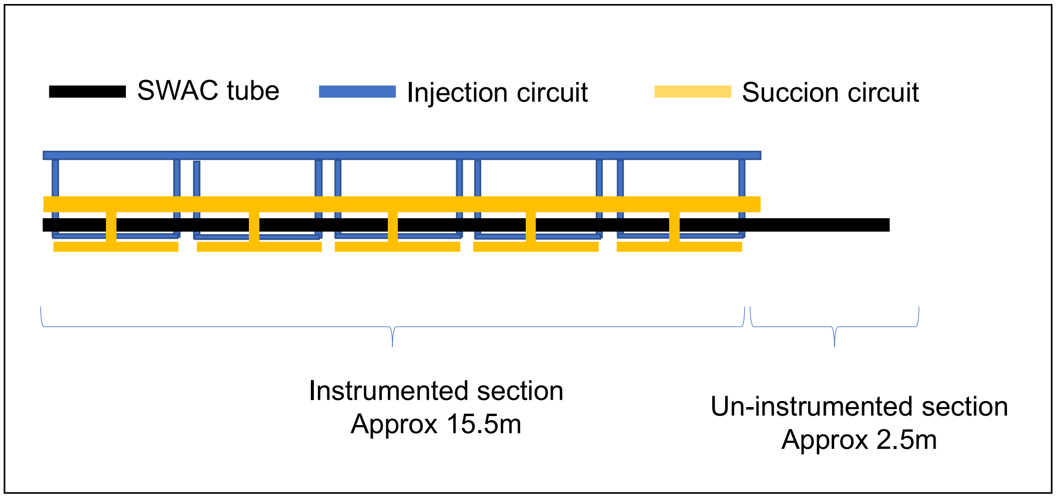


Figure 97: sketch of instrumentation along the pipe

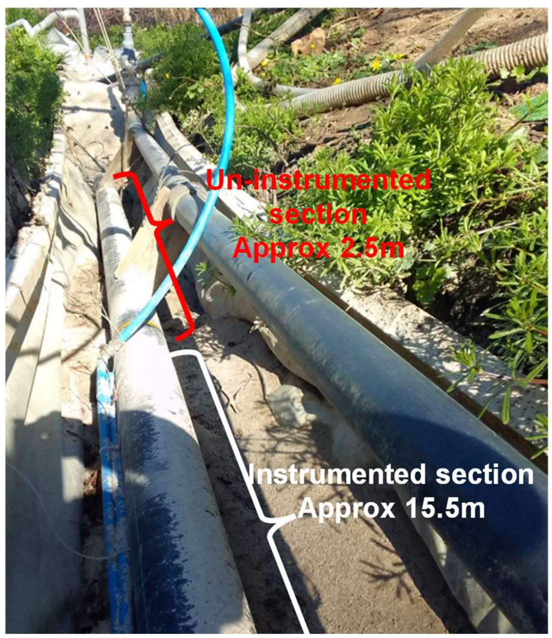


Figure 98: sketch of instrumentation along the pipe

Unit tests were performed with the first section to ensure that the second pump has the expected result (improvement of efficiency of the sandy water suction).

A final test to sink the whole pipe was performed on the last day.

9.9.2. Final test and results

The final test was performed on the 24th of Mars 2023. The test sequence is available in appendix 11. (Section 11.11) and is summarized in the table below:

Step #	Description	Results and observations	Difficulty and subsequent action
1	- Initial set-up of the prototype: - Final inspection - Filling of the trench with water - Start up of the suction in the first section - Start up of the second pump in the river	The first section of the pipe sinks	NA
2	- Opening the 2nd section suction and injectors - Closing the 1st section suction and injectors	The second section of the pipe sinks (less than in first step)	NA
3	- Opening the 3rd section suction and injectors - Closing the 2nd section suction and injectors	NA	The electrovalves were not working as expected and were replaced with manual valves.
4	- Opening the 3rd section suction and injectors - Closing the 2nd section suction and injectors Then - Opening the 4th section suction and injectors Closing the 3rd section suction and injectors	The third and fourth section of the pipe sinks	One of the suction tees was cracked. The trench was emptied in order to repair the suction tee
5	- Filling of the trench with water - Start of injection and suction on the first section, then second, then third one etc		A large crack is again observed on the repaired tee. A new repair was tented but without success.

The following results were obtained:

- The SWAC tube has sunked in the trench and large quantities of sand removed (Figure 99, Figure 100 and Figure 101).
- The un-instrumented section was obviously not buried, which prevented the whole tube to sink entierely (Figure 97)
- The pipe has not sunked evenly: the first section is the one that has sunk the most. Three sinking measures were performed along the pipe: 35cm near the 1st section, 46cm at the middle of the pipe and 12 cm at the end (Figure 102). The explanations to this can be the following:

- Most probably, the un-instrumented section prevented the neighboring section to sink (pipe flexibility limits the sinking)
- It is not expected that suction pump might lose efficiency along the pipe sections but this will have to be confirmed during further tests

Figure 99: view of the pipe sunk in the trench

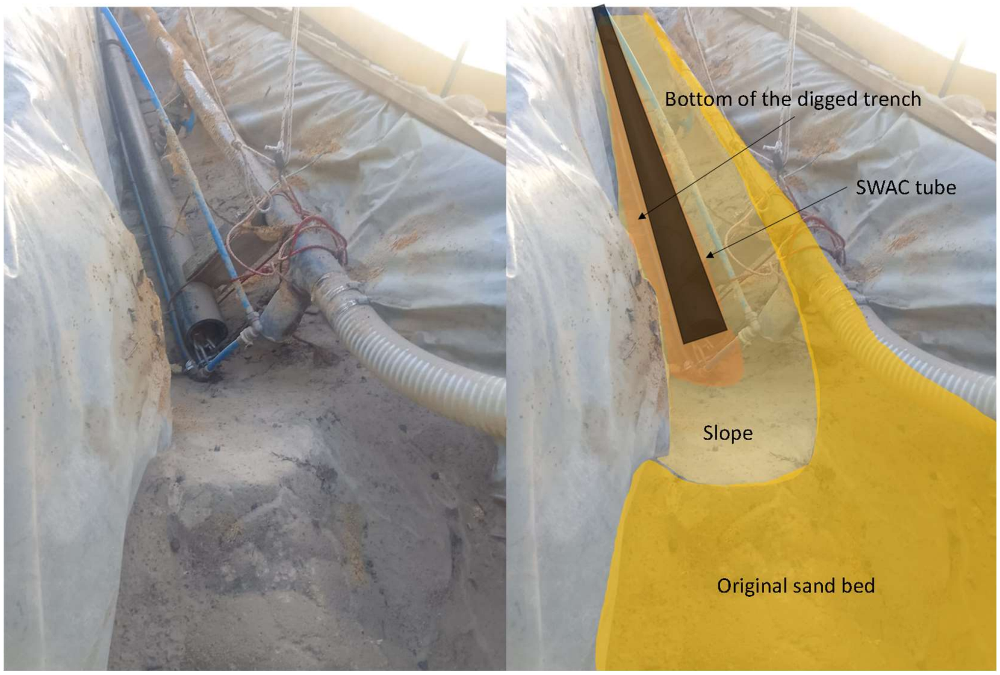


Figure 100: view of the pipe in the trench

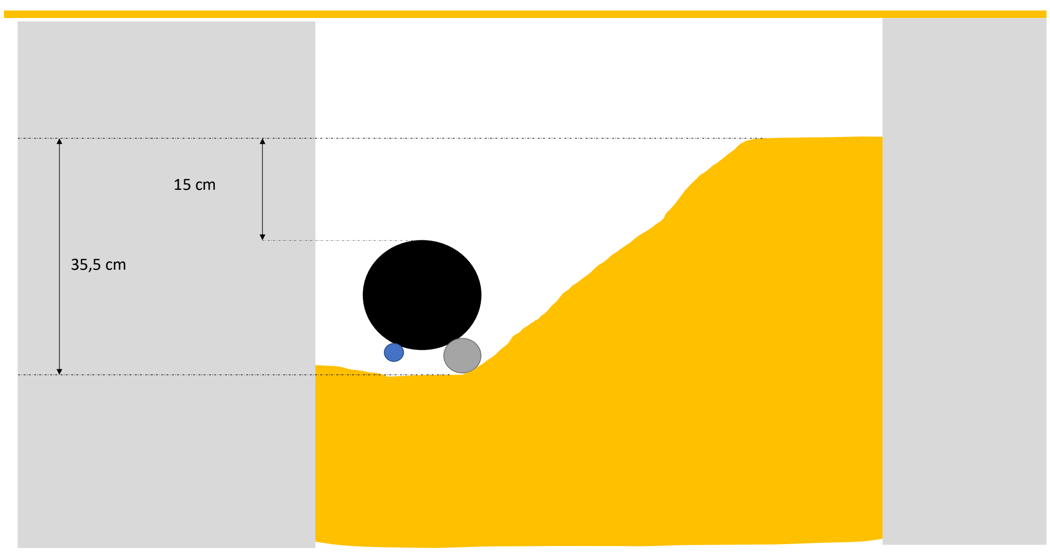


Figure 101: sketch of the resut of first trench burrying

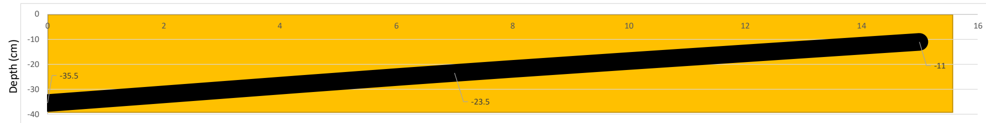


Figure 102: result of the test: instrumented section of the pipe is burried

Figure 103: measurement of burried hight at first section level

10. Conclusions

10.1. First test campaign and optimization of the prototype

The first test campaign started early November and ended early December. Many experiments were performed that permitted to improve the prototype fast and converge to increasingly efficient solutions. The main results of these tests are:

- Injection jets must always be directed below the SWAC tube
- Injection jets must be close to each another to eliminate sand blocks. The distance between them must be reduced by two. It means doubling the jets (24 jets for 2.5 meters, then 46 jets).

The self-burying by section is constrained by the flexibility of the SWAC Tube. As viewed part 6, the prototype can be buried by sections of 6 meters minimum. It implies the design of the water circuit for injection with precise dimensions. The length of the drilled injection bars is fixed to 2.5 meters. Thus, doubling the jets means doubling the holes number on each bar. For that, it is necessary to add a second pump with the same performances.

- The sand suction system is recommended to improve efficiency of the system
- The pressurized air injection is required for the same reasons

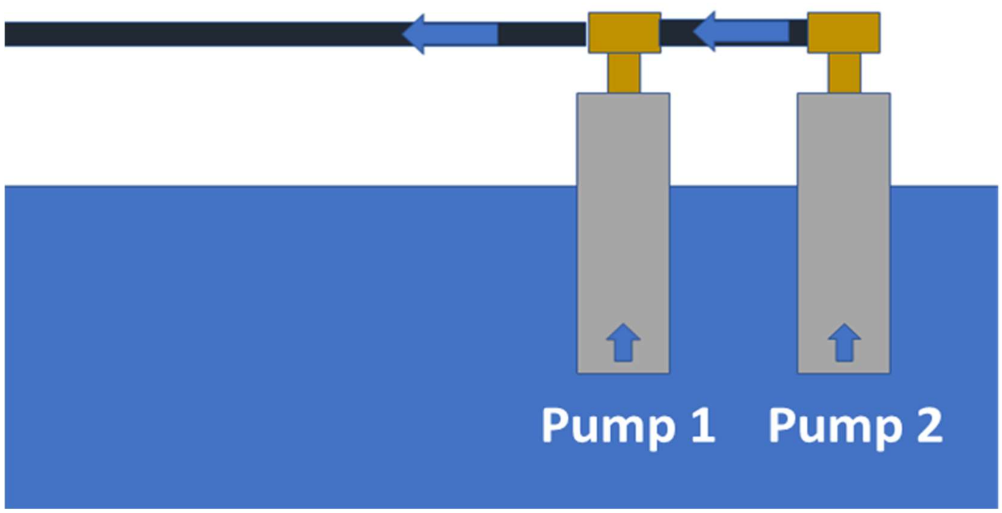


Figure 104 : pumps in parallel in the river to double the water flow rate

If the results on the first section are successful, the test on the whole system will be done.

10.2. March 2023 test campaign and conclusive results

The prototype assembled, optimized and tested was suitable for conducting the tests planned for the EuroSwac project:

- The suction system was operational and efficient.
- The sand suction system was needed but was also the weak point of the model because the suction pump was managed by "ear and eye"
- The sand is well liquefied by the injectors, broken up by the injection of compressed air, and then sucked out properly.
- The removal of the sand induces the sinking of the pipe.

10.3. Way forward

The further **optimization on the prototype** have been identified (tentative tests in summer 2023, out of Euroswac Scope)

- Cut the uninstrumented section of the pipe (Figure 97)
- Replace the rigid suction collector with a flexible corrugated one in order to increase flexibility of the system and thus ease sinking by sections (and reduce iterations) (Figure 105)
- Install a window (= transparent pipe) in the sand apsiration circuit to beer evaluate the quantity of sand sucked up in the water (Figure 106)
- Replace the connectors with more apropriate ones in aspiration circuit in order to reduce pressure losses
- Test with only one pump in order to assess potential optimization

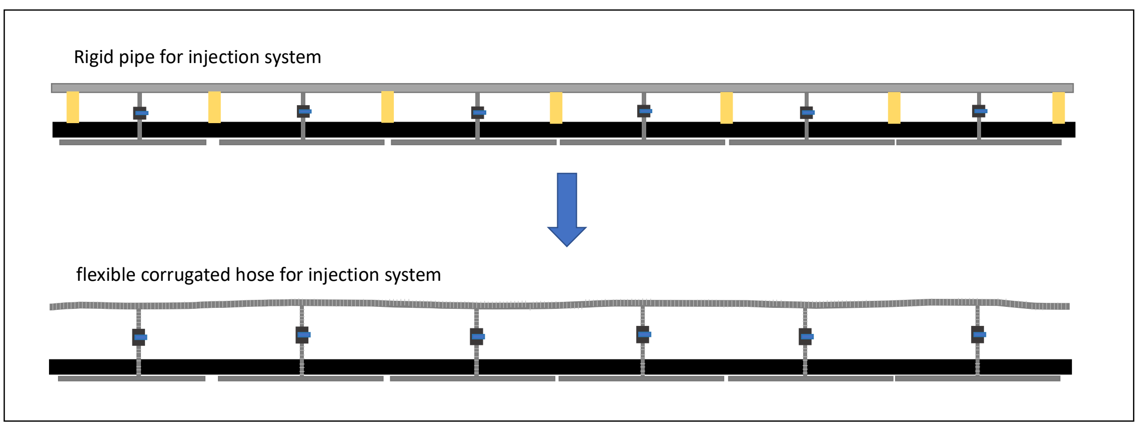


Figure 105: replacement of rigid injection pipe with a flexible corrugated one

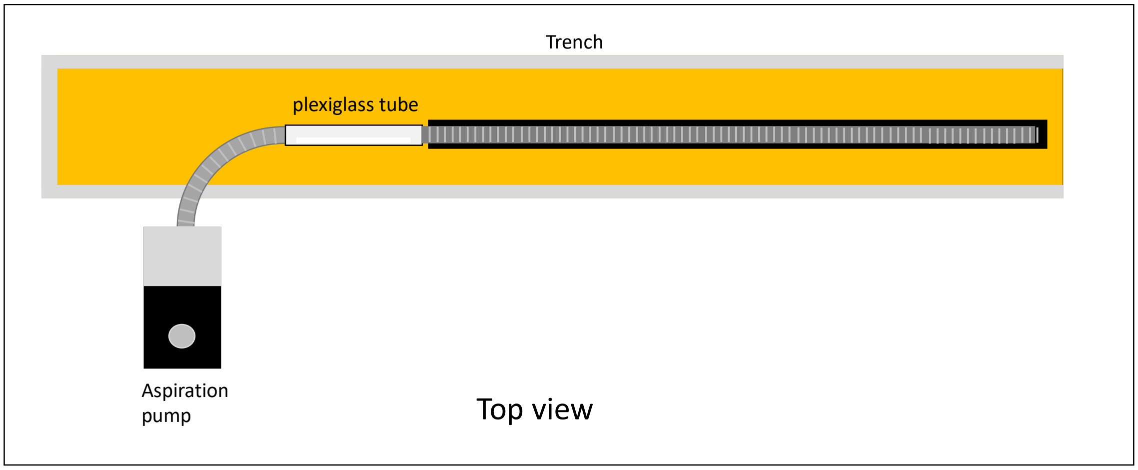


Figure 106: installation of a transparent tube for sand amount visualization

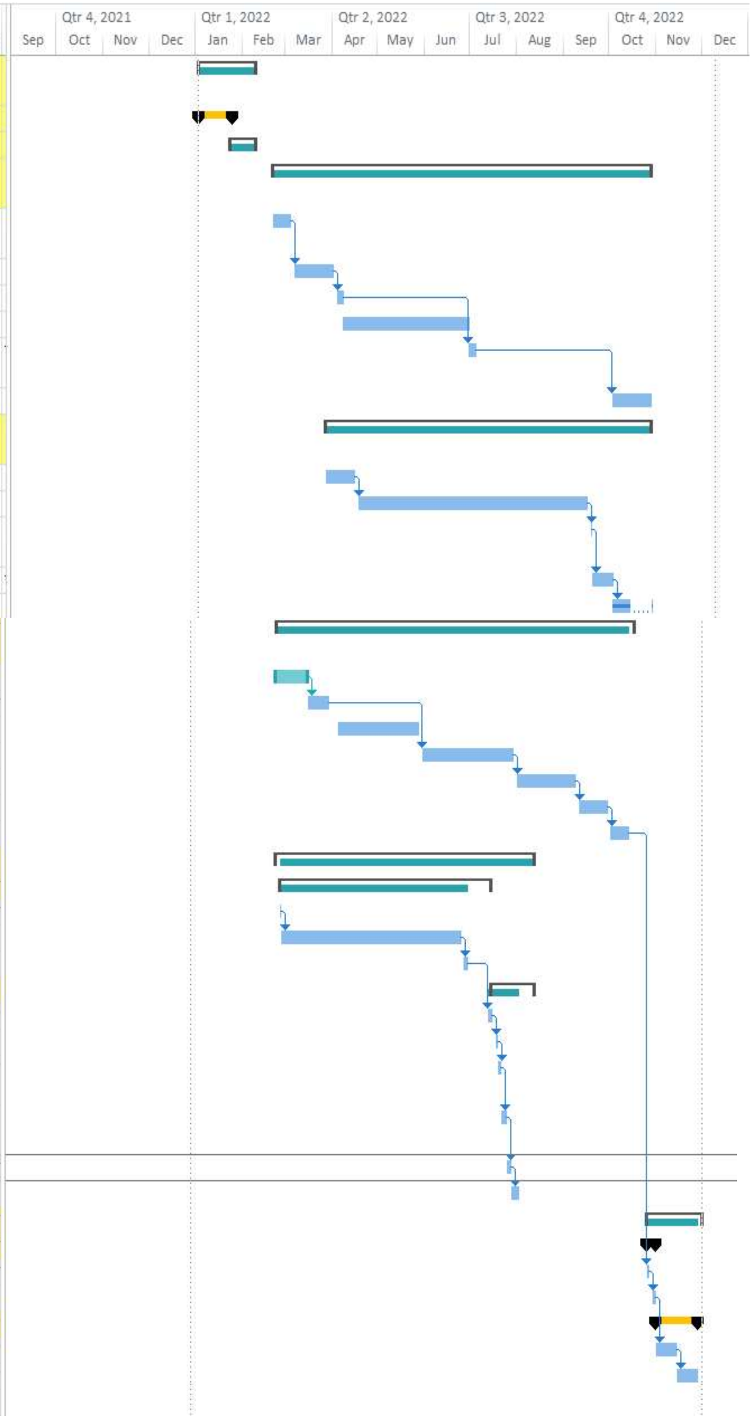
Extrapolation to an offshore environment will require the following measures:

- Choice of materials for injection and suction circuits should be adapted to ensure flexibility of the of connections (PE instead of PVC for instance)
- All connections should be welded to avoid leaks
- Remote control by solenoid valves and relays has not been successful, thus diver-operated ¼ turn valves would be a better solution with limited impact on the cost of the concept.

11. Appendices

11.1. Planning (2022)

	Info	Task Mode	Task Name	Duration
1			CONCEPTION & DIMENSIONNEMENT TUBE SWAC & ACHATS	28 days
2			Dimensionnement du Tube SWAC	16 days
5			Plans & 3D	13 days
8			CONCEPTION & DIMENSIONNEMENT & REALISATION DU SYSTEME HYDRAULIQUE	180 days
9			Bibliographie : répose sable sous impulsion jet d'eau	10 days
10			Dimensionnement (injection et aspiration)	20 days
11			Plans	5 days
12			STAND BY	60 days?
13			Lancement achats (tuyaux, système de connexion et supports)	3 days
14			Test & Calibrage	20 days
15			CONCEPTION & REALISATION DU DISPOSITIF DE MONITORING & COMMANDE	155 days
16			Conception electronique + plans	15 days
17			Programmation	110 days
18			Lancements achats complémentaires (? Et déjà fait?)	1 day
19			Réalisation du montage électronique	10 days
20	✓		Test & debuggage	10 days
21			Préparation & Fabrication du Prototype (et dispositifs de fabrication et de manutention)	171 days
22			Preparation environnement de travail	16 days
23			Fabrication des disposotifs de manutention	10 days
24			STAND BY	40 days?
25			Assemblage Tube PEHD + lests externes	45 days
26			Intégration du système Hydraulique	30 days
27			Intégration du Dispositif Electronique	15 days
28			Test & Calibrage	10 days
29			PREPARATION TRANCHEE POUR TEST	125 days
30			Débroussaillage	101 days
31			Débroussaillage préliminaire	1 day?
32			STAND BY	86 days?
33			Débroussaillage du site de test	3 days
34			Tranchée & Déblai	21 days
35			Tranchée avec une Pelleteuse	3 days
36			Préparation du fond de tranchée	2 days
37			Préparation de la zone de récupération sable aspiré	2 days
38			Mise en place du Polyane dans la tranchée & Zone de récupération	2 days
39			Approvionnement de sable et graviers	3 days
40			Remplissage en sable	3 days
41			TEST AUTO-ENSOUILLAGE	27 days
42			Mise en Place du Prototype	4 days
43			Mise en place du prototype dans la tranchée	2 days
44			Mise en eau de la tranchée	2 days
45			Essais	20 days
46			Test calibrage	10 days
47			Essais	10 days



11.2. REX

Problems		Cause	Solution
Leaks	Flexible suction tube	The silicone did not hold. Not recommended	Silicone replaced by pvc glue
	Connectors	Bowing due to the hyperstatism of some assemblies	Add a layer of pvc glue
	Silted up valves	The manual valves in direct contact with the pumped sand silt up each time they are opened/closed. In the long run, they are almost blocked	Wash the valves regularly
	Threads	Bowing in threads due to the hyperstatism of certain assemblies. The bowing occurs when the guide length is much smaller than the diameter of the threaded tube.	Find the leak (the hardest) and tighten as much as possible
Pierced injection tube	Fire hose	Cause 1) Rotting of the fabric liner due to river moisture Cause 2) Microcracks due to displacement	Flexible tube
	Flexible tube	Simply cracked on 2 cm surely with a sharp tool	We tried to install a fitting, but everything blew up due to the pressure. We replaced the pipe with a DN50 HDPE pipe. We had to buy DN50 to DN40 connectors accordingly.
Electricity	Electrical current	The power supply cable for the two pumps and the compressor was too thin. The electric current induced by the ignition of these three machines was too strong, which systematically stopped the suction pump	Purchase of an additional power strip with thicker cables
	Motorized valve relays	Fine cables cut and completely unnoticed	Tin welding
Too much flexibility	Vacuum manifold	Rubber connectors on the suction manifold were far too flexible and literally fell onto the sand in the trench.	Creation of additional wooden supports

11.3. Team from DORIS Engineering and DeProfundis

DeProfundis :

- Bruno Garnier CEO, SWAC expert and DeProfundis project manager.
- 3 engineers interns : Leonard Brun, Cecilia Rocha, Ghilès Touazi

DORIS Engineering :

- Claire Perez-Thomas – DORIS Engineering Project manager
- Nasser Sadi - Lead
- Norbert Kergastel - Draftman
- Hugo Youssouf--Lacour - Engineer
- François Thiébaud – Sponsor

11.4. First design of the prototype

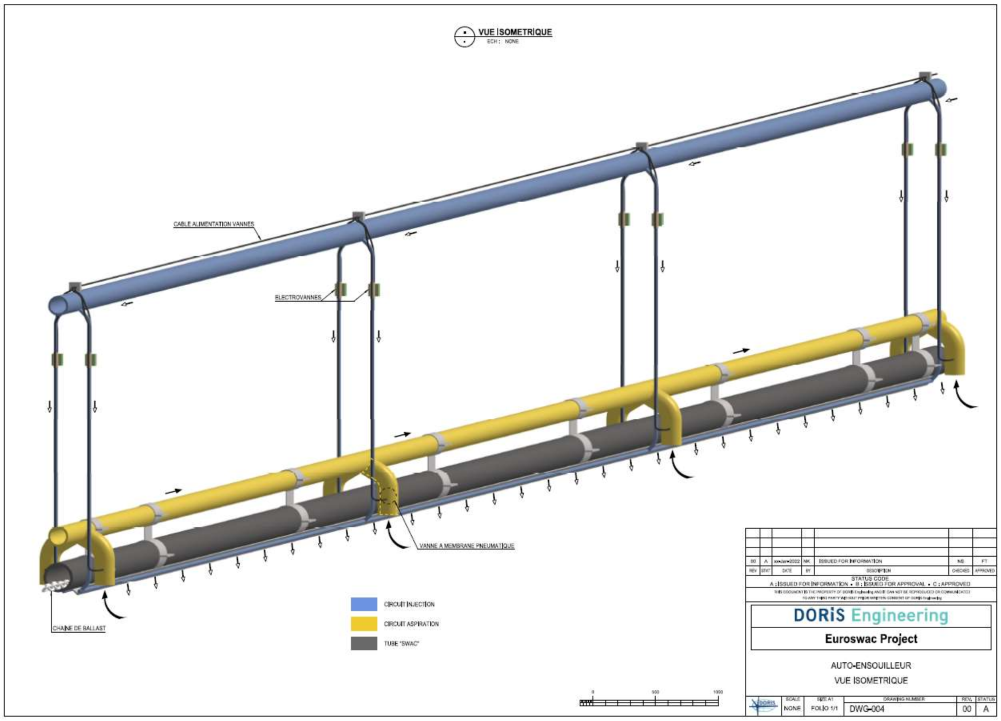


Figure 107 : Plan of the first design of the prototype

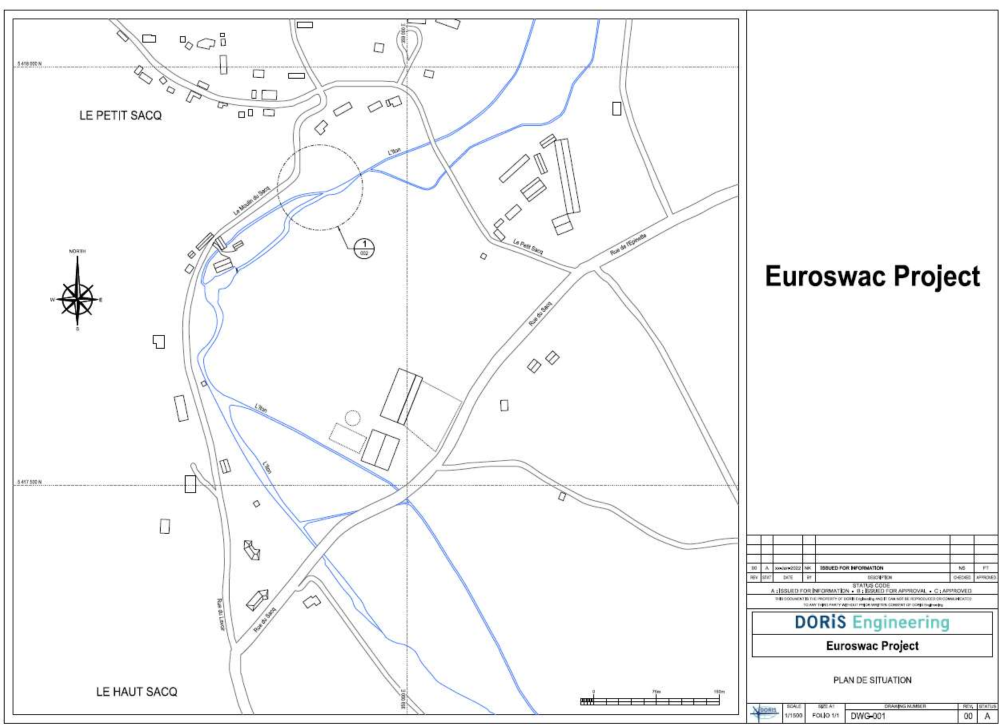


Figure 108 : Map of the site: Mesnil-sur-Iton

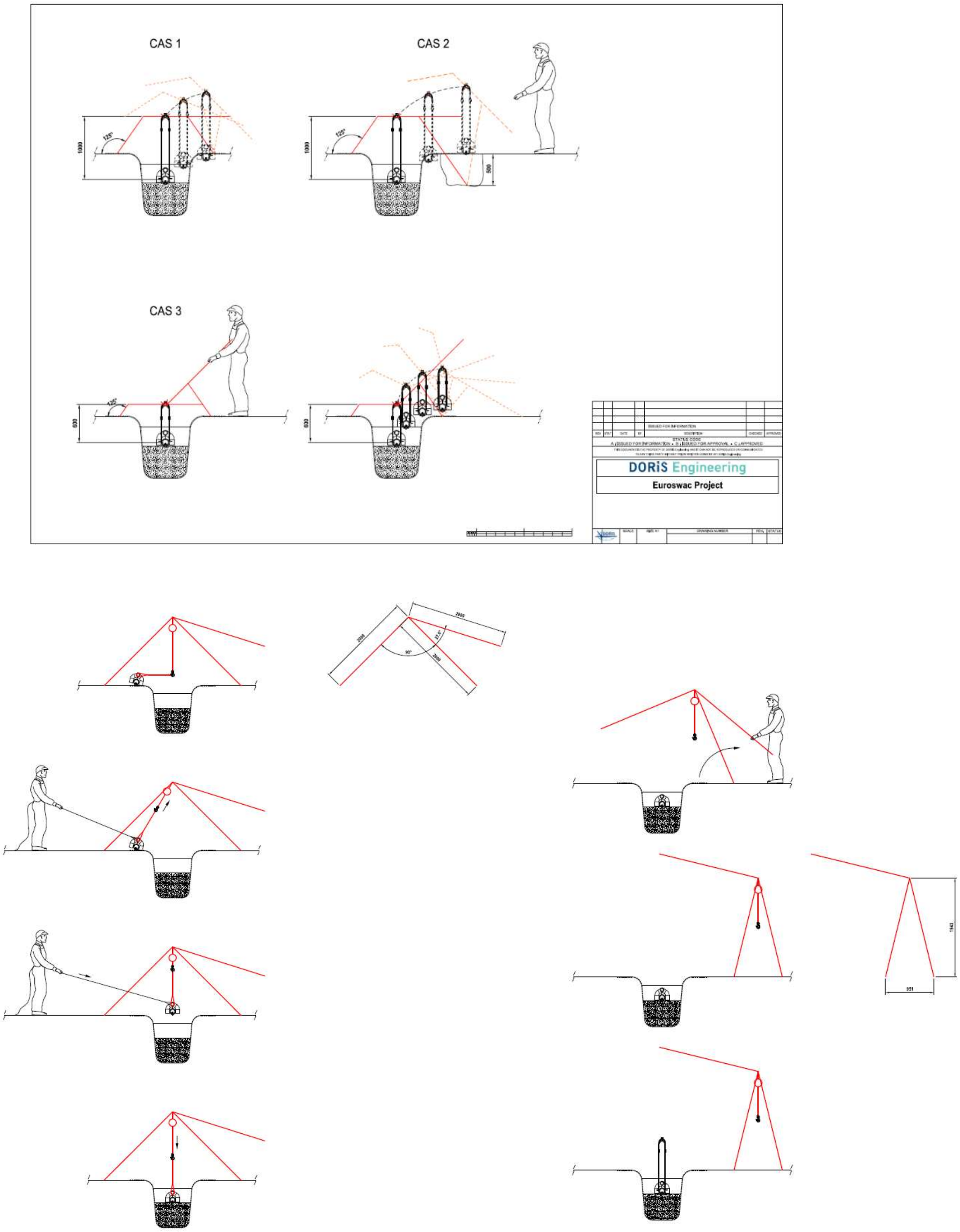
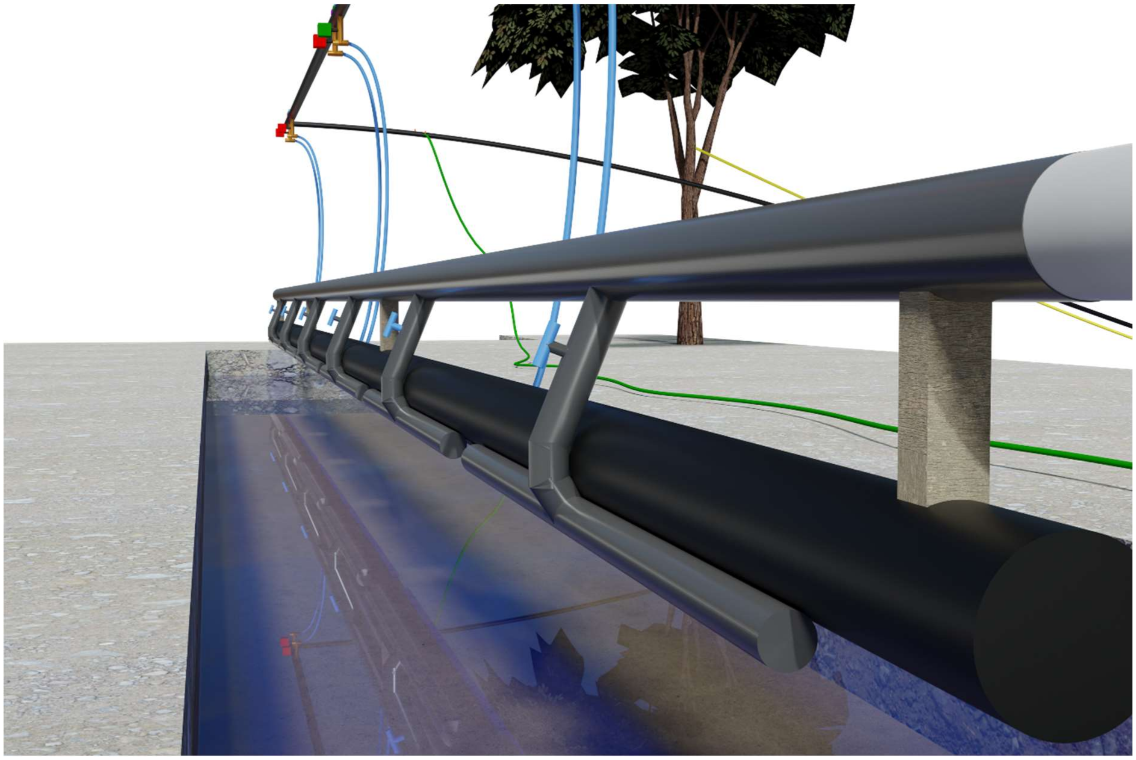
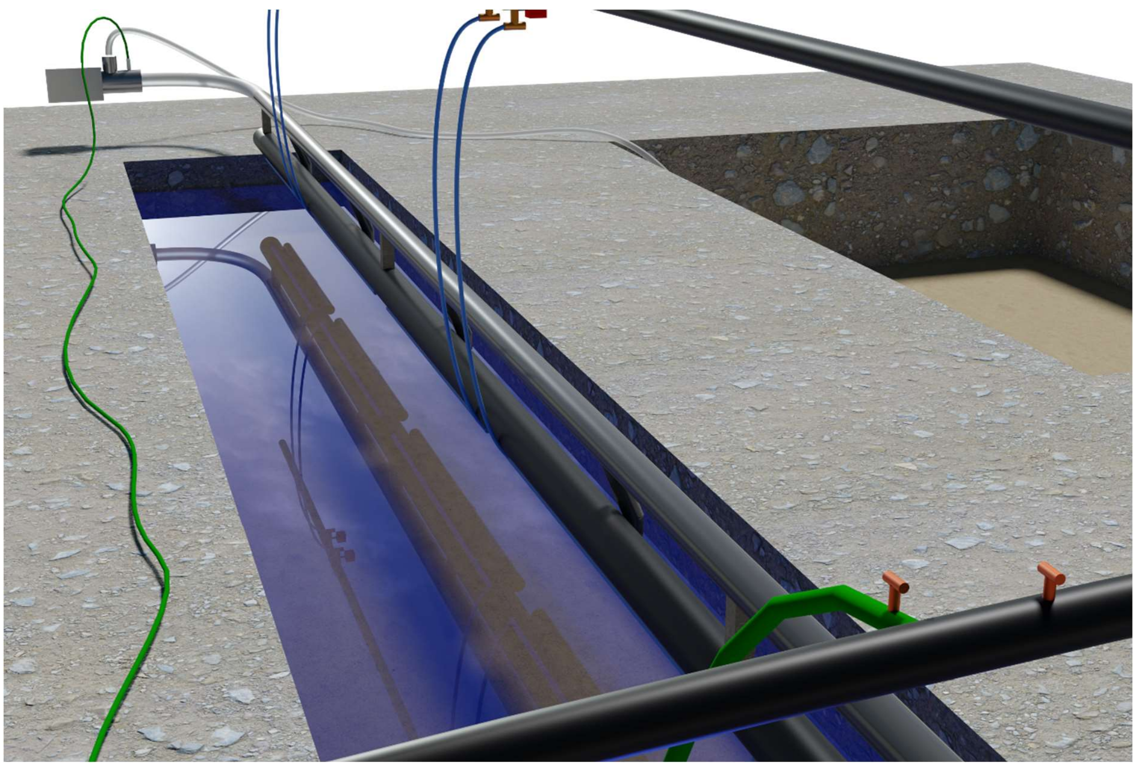


Figure 109 : Diagram of the first handling device

11.5. Actual design of the prototype





11.6. Rigid pipe characteristics

The rigid pipe main characteristics are presented in below table.

Tube HDPE	Young modulus for HDPE =	630 N/mm²	
SDR	**Internal diametre**	**External diametre**	**Thickness**
11,0	0,09 m	0,1100 m	0,01 m
Internal Aire	**External aire**	**HDPE Aire**	**Density**
0,006361725 m²	0,009503318 m²	**0,003141593 m²**	**960 kg.m-3**
W,air,epty	**Buoycy.**	**W,content**	**Sub. wgt**
3,02 kg/m	9,50 kg/m	**6,36 kg/m**	**-0,13 kg/m**

As calculated above, the rigid pipe alone floats above the water. That is why it is ballasted with a metal chain with the main characteristics presented below.

Chain

d	L	W	W,air	W,sub
16 mm	80 mm	56 mm	**16,72 kg/m**	**14,59 kg/m**

Thus, the total weight per meter is 14.46 kg. The pipe dives in the water.

Total

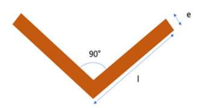
Sub. wgt
14,46 kg/m

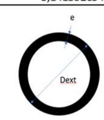
This calculus does not consider the hydraulic system and the other ballasts that will be added later. However, the more the prototype is ballasted, the easier it will dive in the fluidized sand.

11.7. Estimation of the linear mass of the prototype

In order to guarantee that the prototype will not rise to the surface when submerged due to buoyancy, I estimated its buoyancy. And ballast it if necessary. The main components are as follows: The angle iron, the HDPE tube, the water passing through this tube and a steel chain also inside the tube (ballast).

	cornière			Tube (PEHD)			Eau			Chaine		
Données	e	8	mm	e	10	mm						
	l	60	mm	Dext	110	mm	Dint	90	mm			
	ρ	7500	kg/m3	ρ	953	kg/m3	ρ	1000	kg/m3	ρ	7500	kg/m3
	section (m2)	0,000896	m2	section (m2)	0,003141593	m2	section (m2)	0,006361725	m2			
	masse linéique	6,72	kg/m	masse linéique	2,993937799	kg/m	masse linéique	6,361725124	kg/m	masse linéique	10	kg/m
	Volume	0,896	l/m	Volume	3,141592654	l/m	Volume linéique	0,006361725	m3/m	Volume linéique	0,00133333	m3/m
							Volume linéique	6,361725124	l/m	Volume linéique	1,33333333	l/m
							Masse linéique interieur tube	15,02839179	kg/m			





Volume linéique total	0,010399318 m3
masse linéique totale	24,74232959 kg
masse volumique	2379,226226 kg/m3

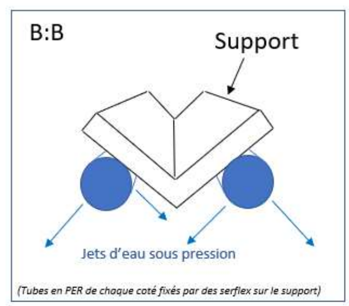
The linear mass of the prototype is thus 24.74 kg/m or 445 kg in total. This is a first estimation with the heaviest elements of the system. The weight of the on-board electronics (sensors and valves) as well as the injection and recovery circuit are not yet accounted for.

11.8. Calculation of the thrust of the water jets on the prototype

It is necessary to ensure that the vertical thrust of the water jets under pressure is negligible compared to the weight of the structure. It could cause the prototype to rise, as it is normally designed to sink into the sand. We model this thrust as follows:

As seen previously, each injection module has four thrust directions. The holes are arranged in two rows on the tube as shown in this diagram:

The angle θ takes two values, 45° for the first row and 135° for the second. The angle α also takes these two values depending on its position on the bar.



Vue en coupe du système

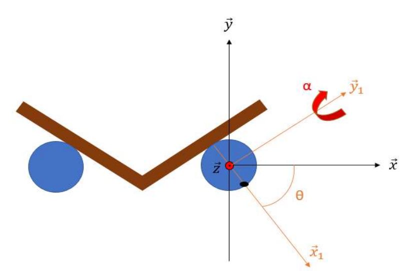


Figure 111 : Vue en coupe de 2 modules

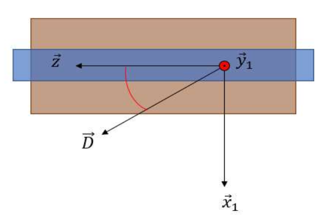


Figure 111 : Vue 0ZX1 du module d'injection avec

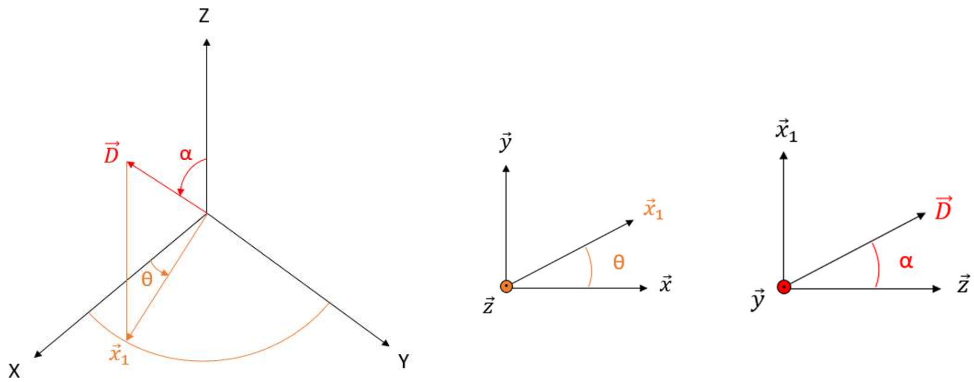


Figure 112 : Repères utiles

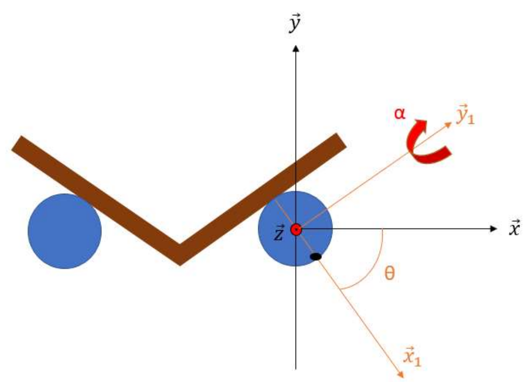
The direction is then calculated by making two successive projections:

$$\overrightarrow{D}(\alpha,\theta) = \sin(\alpha)\,.\cos(\theta)\vec{x} + \sin(\alpha)\,.\sin(\theta)\,\vec{y} + \cos(\theta)\vec{z}$$

We can now calculate the thrust for a hole. According to newton's 3rd law, the principle of action and reaction, water projected with a certain kinetic energy will automatically imply a thrust of the same intensity on the prototype structure.

The thrust force is expressed as: $\overrightarrow{F_{poussée}}(\alpha,\theta) = \rho.Q_v.V_{eau}.\overrightarrow{D}(\alpha,\theta)$ with Q_v the volume flow rate and V_{eau} the velocity of the water as it exits the hole.

This pushing force can also be an asset in a very special case. Self-wetting is only possible if the soil is only sand or with small obstacles. If the pipe encounters a stone in its path, it is not possible to install the pipe. If the problem occurs and is detected (see sensors and actuators section), the idea would be to stop the water flow in one of the left injection modules (arbitrarily) with the electric valve so that the thrust generated by the right tube creates a lateral displacement of the structure which would allow to avoid the obstacle.



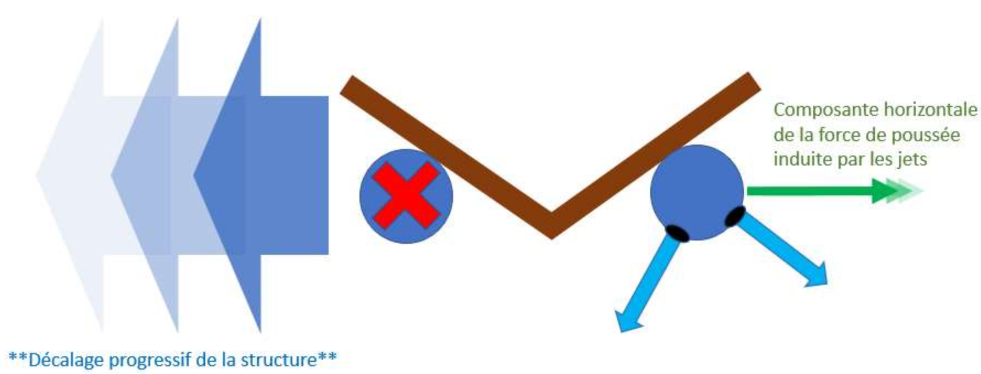


Figure 113 : Schéma de principe

This idea is worth keeping but may not be necessary. In view of the vibrations that the flow of water under pressure will generate on the structure, we can expect that the system will naturally tend towards a stable equilibrium position. In other words, that it gradually shifts itself to avoid the obstacle.

With the following parameters,

rayon tube	0,016 m	
Vitesse	12,50 m/s	
Diamètre du trou	2,00 mm	0,002 m
Qv	0,04 l/s	3,93E-05 m3/s
ρ eau de mer	1024,93 kg/m3	
Masse du tronçon	445,36 kg	
Volume du tronçon	0,19 m3	
Longueur tronçon	18,00 m	
Nombre d'injecteurs exterieurs du prototype	12	
Nombre d'injecteurs interieurs du prototype	12	
Angle alpha d'injection (p.r. horizontale) α	45 °	0,79 rad
Angle Theta d'injection exterieure θ	-45 °	-0,79 rad
Angle Theta d'injection intérieur θ-π	-135 °	-2,36 rad

The vertical and lateral thrusts are calculated for the two rows of holes:

Trou vers l'exterieur	
Force de poussée suivant $\vec{D}$	0,50 N
Force de poussée verticale	-0,25 N
Force de poussée latérale	0,25 N
Force de poussée verticale totale exterieure	**-3,02 N**
Force de poussée latérale totale exterieure	**3,02 N**

Trou vers l'intérieur (angle theta décalé de 90°)	
Force de poussée suivant $\vec{D}$	0,50 N
Force de poussée verticale	-0,25 N
Force de poussée latérale	-0,25 N
Force de poussée verticale totale interieure	**-3,02 N**
Force de poussée latérale totale interieure	**-3,02 N**

Poids du tronçon	-4369,00 N
Poussée d'archimède	1882,10 N
Frottements fluides (négligeables?)	N
Force poussée verticale totale des injecteurs	**-6,04 N**

Ratio Fpoussée/Poids structure	**0,14%**

The total thrust force of the jets under pressure reaches 1.52 N which is very negligible compared to the weight of the structure.

The ratio $\frac{Total\ thru\quad force\ of\ the\ jets\ +Archimedean\ thrus}{Weight\ of\ the\ prototype}$ is 43%. The prototype is thus quite ballasted, it will sink whatever happens.

Force poussée verticale totale d'un tronçon	**-2492,94 N**

11.9. Sand tank and water transfer (not used)

The water transfer tank ⇔ trench mentioned in the introduction has been carried out by a PVC pipe 10cm diameter. Two flanges located at the ends pinch the tank covers to guarantee tightness. Mesh filters minimize the transfer of sand into the pipe. A first attempt with fabric filters turned out to be a failure because the compressed sand on the filter prevented any water transfer.

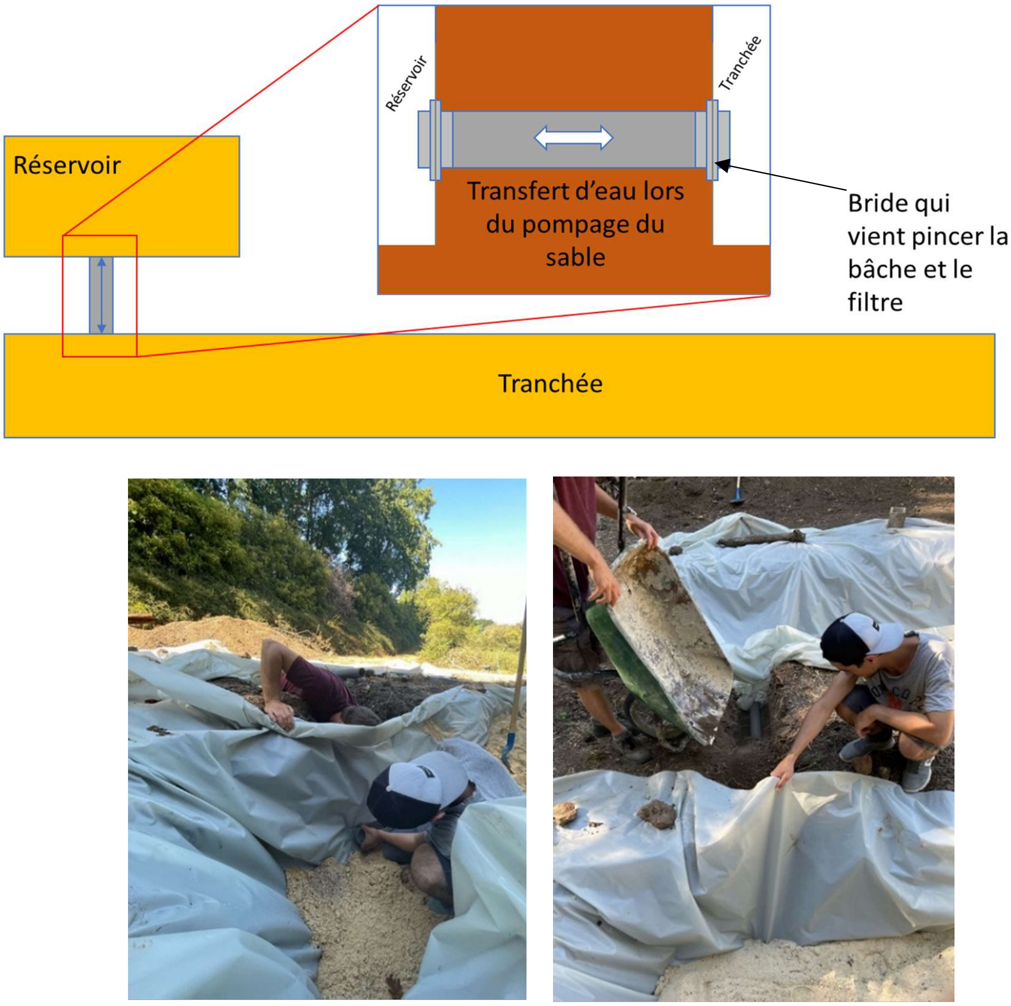


Figure 114 : Trench / Reservoir connection diagram and implementation

The pipe ditch must then be backfilled to equalize the pressure on the two tarps. After filling the trench with sand and water, we faced several problems. First, holes not visible in the tarp are to be deplored because of the weight of the contents. The water empties in a few hours which is not very restrictive, it will suffice to add water accordingly each hour.

11.10. Tutorial

Arduino Serial Port Buffer Size Mod

Arduino Serial Port Buffer Size Mod

Whilst developing the software for our Arduino based Serial Graphic TFT Display a problem with transmitting too much data at once occured. When using our TFT display we expected the controlling program to send a big burst of serial data initially to set various configuration settings on the screen and to display a screenfull of data.

The Arduino core code contains a nice little round robin data buffer where you can keep throwing data at it and the arduino code will read the data and process it in order. However, this data buffer is by default only 64 bytes in size. This value is hard coded in the Arduino core source code and applies to all Arduino boards, even those with a vast amount of RAM available.

The 64 byte limit meant that sending a burst of data longer than 64 bytes would cause data to be truncated as the ATmega328 could not process the data sent fast enough.

The solution is easy, increase the buffer size to 256 bytes.

This is easy enough to implement but is a real pain because the Arduino core code which includes this setting is compiled before your actual program code is, so you cannot simply setup a #define or similar function to be able to select buffer size at compile time.

We found a number of convoluted methods on the internet which claim to work, but we thought an easier solution might be of use to others who need to increase the buffer size. The method described below is the option we chose to implement, and while not exactly elegant is easy to use and understand.

Solution

The solution is to create a complete copy of the arduino core code (it's really not that big and disk space is cheap), modify the buffer size in the new core code and then to create a new board which is listed in the Arduino IDE which uses this new core directory. The steps to follow are as follows..

The whole of the Arduino core code is located in a directory similar to

```
C:\Program Files\arduino-1.0.1\hardware\arduino\cores\arduino
```

Make a complete copy of this directory and save it to

```
C:\Program Files\arduino-1.0.1\hardware\arduino\cores\arduino_256_serialbuf
```

The hard coded buffer size is stored in a file called **HardwareSerial.cpp** (or **USBAPI.h** in more recent versions)

Here is the standard definition located near the top of the file

Here is the standard definition located near the top of the file

```
#define SERIAL_BUFFER_SIZE 64
```

Edit the HardwareSerial.cpp file in the new directory and modify the buffer size

```
#define SERIAL_BUFFER_SIZE 256
```

Now we need to add an option to the **boards.txt** file to use this new directory. The boards.txt file should be in a directory similar to

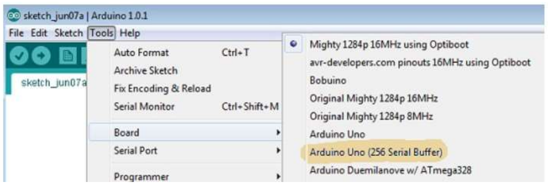
```
C:\Program Files\arduino-1.0.1\hardware\arduino
```

Below is part of the boards.txt file. The first section is for the standard Arduino Uno. We have added a section below it which will display in the Arduino IDE as **Arduino Uno (256 Serial Buffer)**. You can see the core directory is referenced to our new directory with the modified file (uno256.build.core=arduino_256_serialbuf)

```
##############################################################

uno.name=Arduino Uno
uno.upload.protocol=arduino
uno.upload.maximum_size=32256
uno.upload.speed=115200
uno.bootloader.low_fuses=0xff
uno.bootloader.high_fuses=0xde
uno.bootloader.extended_fuses=0x05
uno.bootloader.path=optiboot
uno.bootloader.file=optiboot_atmega328.hex
uno.bootloader.unlock_bits=0x3F
uno.bootloader.lock_bits=0x0F
uno.build.mcu=atmega328p
uno.build.f_cpu=16000000L
uno.build.core=arduino
uno.build.variant=standard

##############################################################

uno256.name=Arduino Uno (256 Serial Buffer)
uno256.upload.protocol=arduino
uno256.upload.maximum_size=32256
```

```
uno256.upload.speed=115200
uno256.bootloader.low_fuses=0xff
uno256.bootloader.high_fuses=0xde
uno256.bootloader.extended_fuses=0x05
uno256.bootloader.path=optiboot
uno256.bootloader.file=optiboot_atmega328.hex
uno256.bootloader.unlock_bits=0x3F
uno256.bootloader.lock_bits=0x0F
uno256.build.mcu=atmega328p
uno256.build.f_cpu=16000000L
uno256.build.core=arduino_256_serialbuf
uno256.build.variant=standard

##############################################################
```

That's all you need to do. Now when you want a larger serial buffer (for a specific board) you just choose this as the board in the Arduino IDE and compile as normal.



11.11. Final test details

This appendix provides François Thiébaud notes of the final test performed on the Friday 24th March. This report is only available in French.