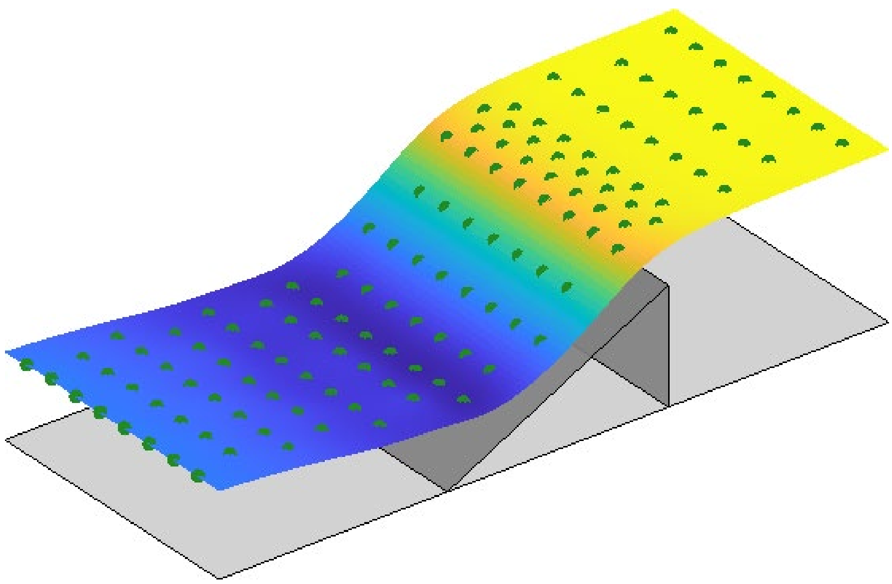
VAMONOS - Vertically-averaged models for non-hydrostatic flows

Open-channel flow over weirs. Experimental data.

02/07/2021



Content

1. Introduction

This dataset contains the results from the tests carried out at the hydraulics laboratory of the Civil Engineering School, at University of A Coruña (Spain), as part of the VAMONOS (Vertically-averaged models for non-hydrostatic flows) project (CTM2017-85171-C2-2-R). The aim of the project is the development of enhanced 2D river flow models including additional terms to account for non-hydrostatic pressure and mixed flow conditions around hydraulic structures.

This data package includes experimental results on 9 different weir geometries that were tested in an open channel. The experimental facility consists of a 15 m flume with a square cross section of 0.5 x 0.5 m. Water depths were measured with an automatic data acquisition system on a grid of approximately 125 points. Each weir was tested under two different flow conditions: free and partially submerged condition. In all the tests the inlet discharge was close to 30 l/s.

The package includes both, the raw data measured during the experiments, and processed data that has been filtered and averaged in order to obtain the water depth in a grid of locations for each test. Those interested in experimental data for the calibration of numerical models or the analysis of empirical discharge rating curves are suggested to work only with the data included in the folder *Processed_data.* The scripts contained in the folder *Matlab_files* are just needed for those who want to work with the raw data.

2. Experimental facilities

2.1. Hydraulic flume

The tests were carried out in the open flume of the hydraulics laboratory. It is a rectangular flume with a cross-section of 0.5 x 0.5 meters and 15 meters length (Figure 1). The structure is made of steel and methacrylate. Its hydraulic circuit can provide a maximum discharge of 50 l/s with a variable bottom slope, although in all the tests presented here the slope was fixed to 0.0%. At the end of the flume the flow is controlled with a sluice gate.

Figure 1. Hydraulic flume and sluice gate.

2.2. Weirs

Nine different weirs were tested in the experiments, all of them made of stainless steel. The different weir geometries analysed are shown in Figure 2 and identified in Table 1.

Table 1. Weirs tested.

Name	Weir
Duckbill	1
Double rectangular	2
Rectangular	3
Rectangular with slope	4
Diagonal 30	5
Diagonal 45	6
Diagonal 60	7
Diagonal 30 with slope	8
Diagonal 45 with slope	9

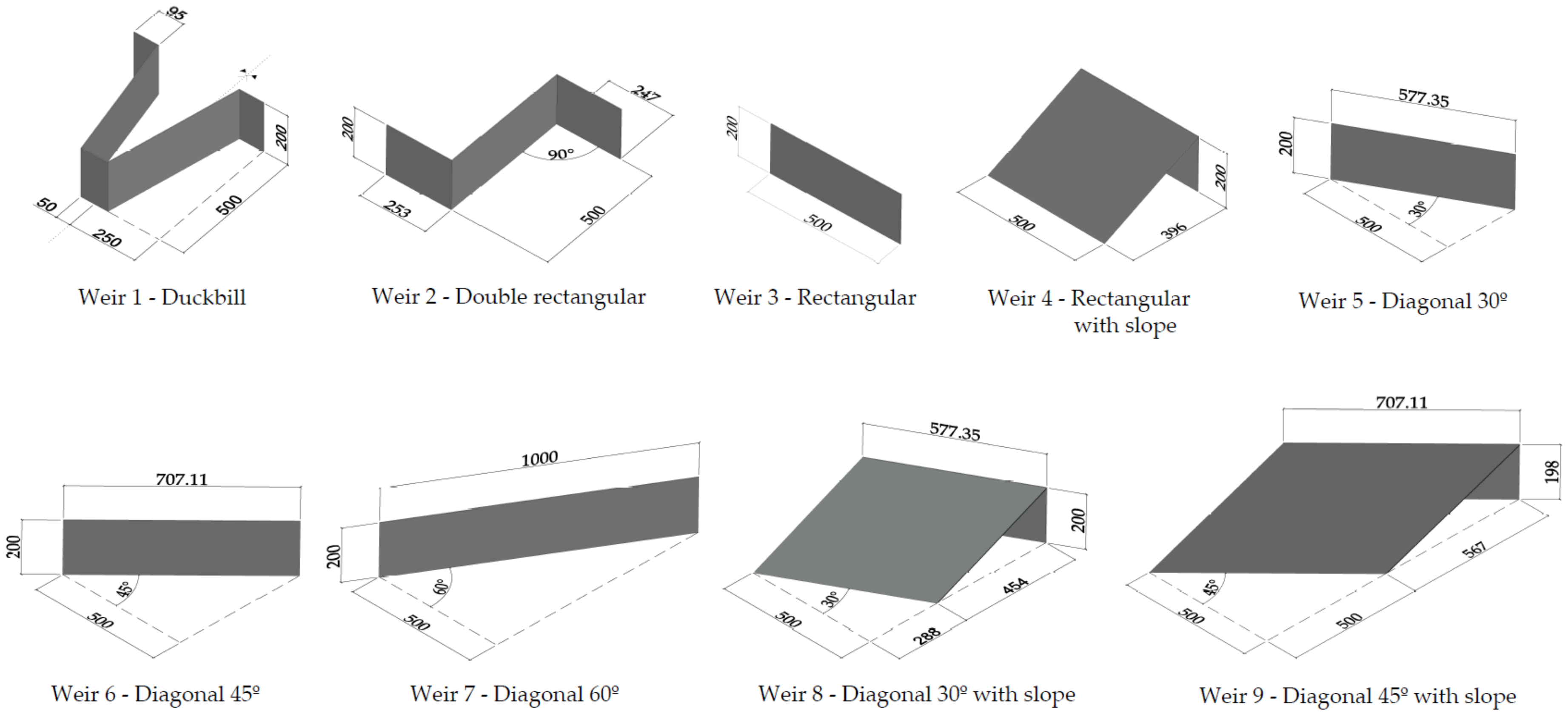


Figure 2. Weir geometries.

2.3. Automatic data acquisition system

The water depth was measured on a grid of points with an automatic data acquisition system based on an automatic positioner and a hydraulic piston (Figure 3). The positioner moves a piston in the X- and Y-axis, while the piston moves up and down (in the Z-axis) continuously in order to make measurements of the water depth.

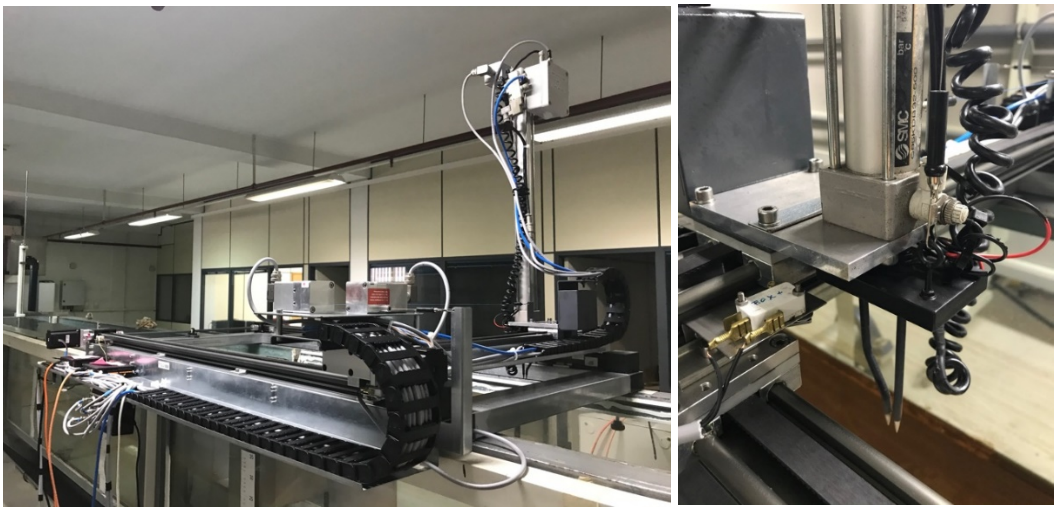


Figure 3. Structure formed by the automatic positioner and the piston.

As shown in Figure 3, the piston has two needles that are attached to a rectangular plate, which in turn is attached to the vertical piston. When the two needles touch the water surface an electrical circuit is closed and the piston moves up.

In each of the axes of the structure formed by the positioner and the piston, a wire sensor is established that transforms the lengths into voltage. The voltage of these sensors is recorded by a National Instruments data acquisition module. Thus, the raw data files contain voltage data that must be transformed into distance.

An Arduino board sends the motion commands to the stepper motors through two controllers (X-axis and Y-axis). Each controller is connected to a stepper motor. In all the tests, water depth measurements were taken at the locations defined by a grid whose dimensions are 400 mm wide and 1155 mm long. The automatic positioner carries the piston from downstream to upstream, taking several water depth measurements at the requested coordinates. The piston draws an "S" shaped path, as it is shown in Figure 4.

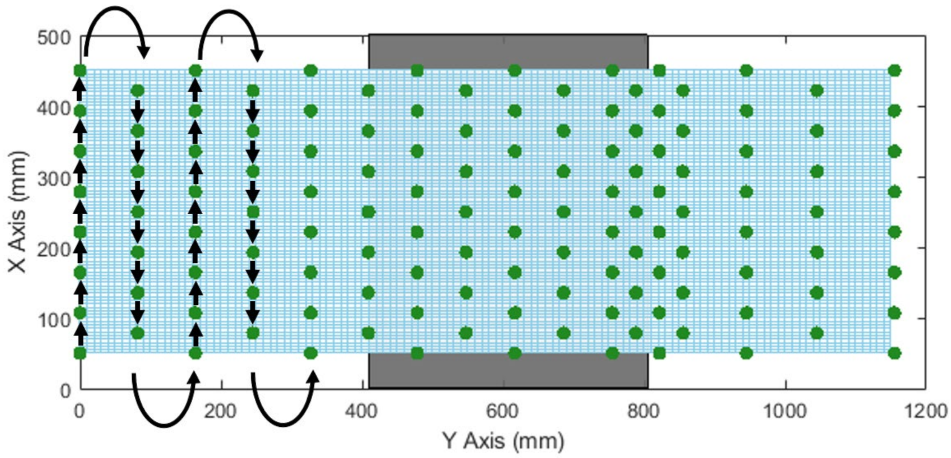


Figure 4. S shaped path.

The piston takes measurements up to a distance of 50 mm from the flume lateral walls, i.e. although the cross section is 500 mm wide, the minimum and maximum values in the X-axis are approximately 50 mm and 450 mm respectively.

3. Experimental methodology

Two boundary conditions were tested for each weir. In all cases an attempt was made to maintain the inlet discharge close to 30 l/s. The downstream boundary condition was varied from one test to another in order to obtain partially submerged and free discharge conditions. The bottom of the channel was in all cases in a horizontal position (0.0% slope). Although the measurement grids have been adapted to each weir geometry, all of them include approximately 125 data points.

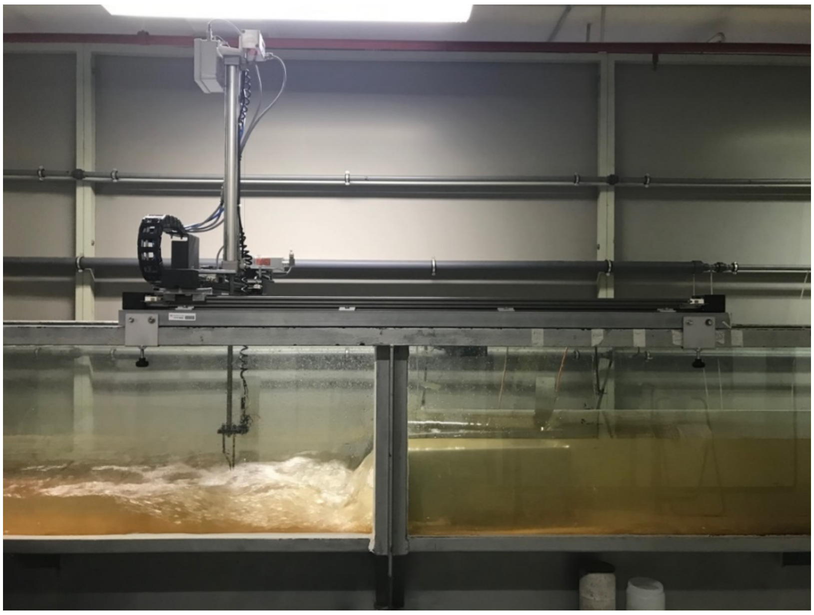


Figure 5. Photo taken during one of the tests.

Table 2 includes the boundary conditions of the 18 experimental tests. The water depth value upstream and downstream of the weir refers to the average water depth of the first and last row of points measured by the automatic data acquisition system. In addition, the document *Summary_tests.pdf* includes a visual and brief summary of all the tests.

Table 2. Flow conditions for each experimental test

Weir	Test	Flow condition	Flow rate (l/s)	Water depth downstream of the weir (mm)	Water depth upstream of the weir (mm)
1	1	Free	29.16	110.70	251.96
	2	Submerged	29.18	168.44	249.20
2	1	Free	29.21	111.80	262.14
	2	Submerged	28.41	171.85	260.62
3	1	Free	29.07	152.84	293.14
	2	Submerged	29.00	225.83	297.16
4	1	Free	28.03	146.96	283.10
	2	Submerged	28.29	229.01	288.80
5	1	Free	28.29	130.80	291.15
	2	Submerged	28.92	219.80	292.93
6	1	Free	29.06	128.93	273.94
	2	Submerged	28.99	213.08	277.39
7	1	Free	31.94	118.40	265.18
	2	Submerged	31.90	175.35	265.41
8	1	Free	28.90	134.88	280.54
	2	Submerged	30.47	210.22	283.68
9	1	Free	31.88	111.43	275.94
	2	Submerged	30.45	220.06	274.50

3.1. Data filtering

Since the voltage data acquisition is done with a frequency of 1000 Hz. This signal was filtered in order to eliminate the information recorded when the needles are not in contact with the water.

For each measurement point, the X- and Y-coordinates are averaged during the time at which water contact occurs. Regarding the Z-coordinate, its value is recorded each time that the needles contact the water surface. In that way, data value is calculated for each grid point by averaging all the X, Y, Z measurements taken at the corresponding point.

3.2. Calibration of the axis

As mentioned above, the automatic positioner has 3 wire sensors (one per axis) that enable the measurement position to be related to a voltage value. In order to establish the relation between voltage and distance, the transformation equations were calibrated.

For the X- and Y-axis, the equations have been calculated only once at the beginning of the test campaign. To do that, 3 points were taken on each of the axes. Once the value in voltage and in millimeters of these 3 points is known, a linear relation is established. Figure 6 shows how these linear equations were estimated. These two equations are directly implemented in the file that reads the test results.

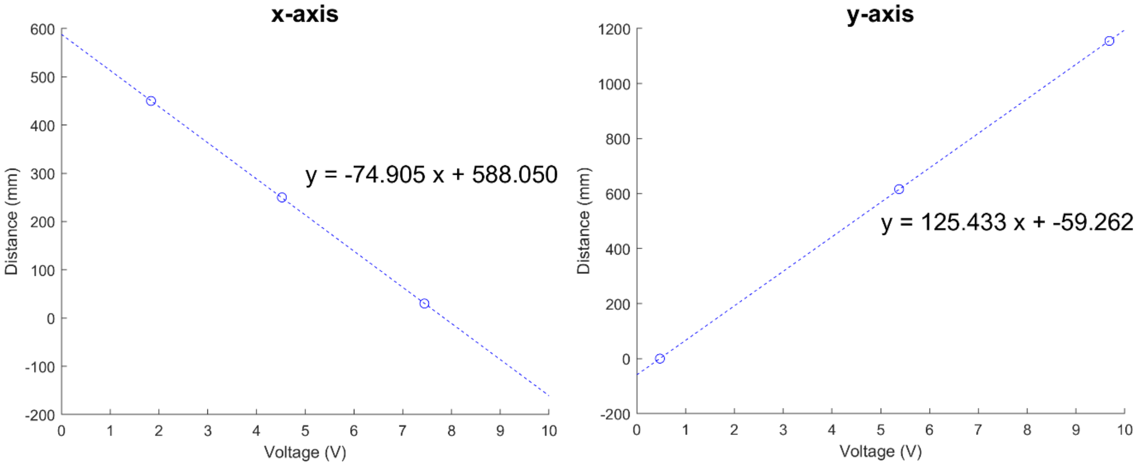


Figure 6. Voltage-distance transformation equations.

The calibration of the Z-axis is carried out for each of the tests independently. Before the beginning of each test, the voltage values corresponding to 4 points on the Z-axis were recorded. The location of the first and last points are the same in all the tests, while the 2 intermediate points are modified in each test. The Matlab reading files provided with this package include all the information needed for data processing. The “Zcalibration” function has been included in order to process the voltage data of the calibration files and to build the equation used to read the test results.

3.3. Relative error on depth and number of measurements per grid point

Using the Weir 4 (Rectangular with slope) as a representative test, four locations were chosen in characteristic areas of the flume (upstream and downstream the weir), and 300 depth measurements were taken at each location. Taking the average value of these 300 measurements as the target value, the relative error obtained by computing the mean depth with 2, 3, 4, …, 299 measurements was calculated. In this way, a relation between the number of measurements and the relative error on depth was obtained. Table 3 shows this relation both, upstream and downstream the weir.

In order to obtain a relative error of less than 5%, the measurement campaign was designed in order to obtain a minimum number of 12 measurements at each of the points located downstream of the weir: taking approximately 13 measurements in very low turbulence areas, and increasing this value to approximately 36 measurements in low-medium turbulence regions and to 64 in the most turbulent areas of each test. This configuration allows us to reduce the relative error on depth to a maximum value of 5%.

Table 3 Relation between the maximum relative errors and the minimum number of measurements required.

Maximum relative error (%)	Upstream of the weir	Downstream of the weir
5	1	12
3	1	20
2	1	33
1	2	105
0.5	5	142

4. Uploaded files

The files included in this package are structured in the following three folders:

- Raw_data
- Matlab_files
- Processed_data

Those interested in experimental data for the calibration of numerical models or the analysis of empirical discharge rating curves, are suggested to work only with the data included in the folder *Processed_data.*

The folder *Raw_data* contains 9 subfolders (one for each weir geometry). Each of these subfolders contains the data recorded during the weir tests (free and partially submerged case). The recorded test data consists of 8 files: 3 files generated before the test to calibrate the Z-axis in post-processing ("zcalibration"), 3 files generated during the test itself with the voltage data measured along the points of the grid ("mesh"), and 1 file with the recorded rate flow data ("Flow"). Together with these recorded files, a photo taken during the test has been added in each test folder.

The folder *Matlab_files* contains three m-files: one used for data processing (*TestReader.m)* and two functions called from the previous file (*DrawWeir.m* and *Zcalibration.m*). Using these scripts and following the prompts, figures can be generated to analyze the result of each test easily (Figure 7). *TestReader.m* is divided into 4 sections that allow the user to process the raw test data, generate 2D and 3D figures with the results, and generate a text document with the test result.

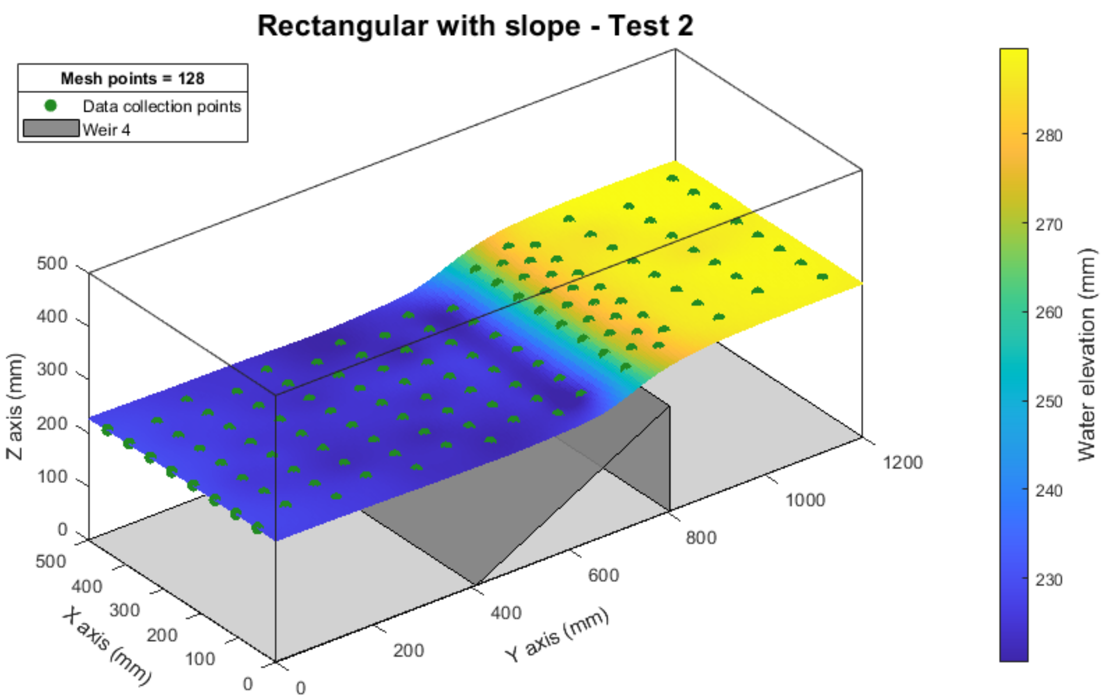


Figure 7. Example of 3D figure representing the water surface elevation measured in one of the experimental tests.

The folder *Processed_data* contains the already processed water depth results for each test, and is divided into 9 subfolders (one per weir). In each of these folders it is possible to find the following files:

- A PDF document that defines the weir geometry and its position with respect to the coordinate origin used in the corresponding test.
- A text document with the results of the free discharge case: Average flow, average value of the water level at Y=0 section, and X, Y, Z coordinates of each grid point. In addition, the minimum Z-value, the maximum Z-value and the variance in the vertical direction of each point are also included.
- A text document with the results of the submerged discharge case: Average flow, average value of the water level at Y=0 section, and X, Y, Z coordinates of each grid point. In addition, the minimum Z-value, the maximum Z-value and the variance in vertical direction of each point are also included.