E-proceedings of the 38th IAHR World Congress
September 1-6, 2019, Panama City, Panama
doi:10.3850/38WC092019-1042

EXPERIMENTAL INVESTIGATION ON TRANSLATIONAL VELOCITY AND AIR POCKETS VOLUMES ASSOCIATED WITH PRESSURE TRANSIENTS IN RECTANGULAR CONDUITS OF STORMWATER SYSTEMS

JULIANA KAIBER DA SILVA(1), HENRIQUE SOARES GOETZ(2), GIANE GÓES(3), JOSE G. VASCONCELOS(4), ROGÉRIO DORNELLES MAESTRI(5), ANA LUIZA DE OLIVEIRA BORGES(6)

(1,2,3,5,6) Institute of Hydraulic Research, Federal University of Rio Grande do Sul, Porto Alegre, Brazil
juliana.kaiber@ufrgs.br

(4) Department of Civil Engineering, Auburn University, Auburn - Al, United States
jgv0001@auburn.edu

ABSTRACT

Severe structural damages in stormwater systems are related to two-phase unsteady flows and interactions between air and water phases. The entrapment of air pockets in stormwater systems may be triggered during the transition between free surface to pressurized flow regimes. This paper presents an experimental investigation concerning the movement of air pockets through a geometrical singularity present in the system. The experiments were accomplished in a physical model located at the Federal University of Rio Grande do Sul (Porto Alegre, Brazil). The results indicate that non-negligible pressure oscillations may be expected in the system when an air pocket passes through a geometrical singularity.

Keywords: Air-water interactions, two-phase unsteady flows in stormwater systems, hydraulic physical modelling, geometrical singularity

1 INTRODUCTION AND OBJECTIVES

During severe rain events, the flow in stormwater systems may undergo pressurized and usually biphasic conditions are also observed in these systems. Significant amounts of air may be entrapped inside the conducts during the transition between free surface and pressurized flow regimes or due to unsteady flow interaction with geometric constrains of the system. Despite being an important and common feature of unsteady flows in stormwater systems, biphasic unsteady flow conditions are generally disregarded during its conception and design phases

Usually, urban drainage systems are adapted to the layout of streets and avenues and to the provision of other elements of urban infrastructure, such as water supply systems, sewage systems and gas supply systems. The joints or geometric singularities of the system as will be mentioned in this work, are elements commonly used by the designers in the task of arranging the drainage system in the urban context.

Changes in flow direction, changes in the bottom slope of the conducts, geometric differences in the base or at the top of the conduits, widening and narrowing, or any other point in the system used to adapt cross-sectional characteristics is understood as geometric singularities of the system. Despite its abundance in the stormwater systems, it is not common to find studies that relate the geometric singularities to functional and structural failures.

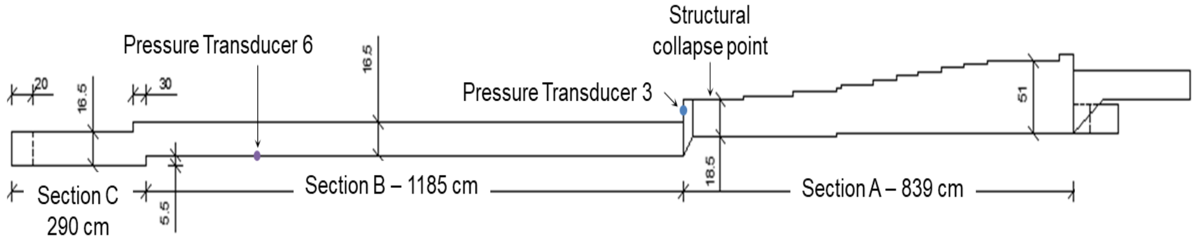
The present experimental research explores the importance of geometric singularities considering two-phase unsteady flows in stormwater systems.

2 METHODOLOGY

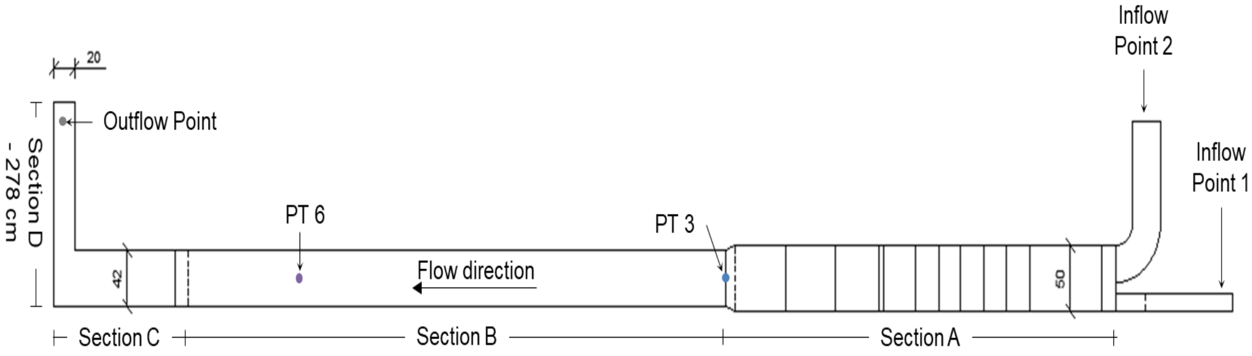
2.1 Experimental Setup

The experimental setup is a reduced-scale model that reproduces a long section of a real stormwater system that has presented a structural collapse in February 2013. The adopted scale was 1:15 and Froude Number similarity criterion was considered to select the range of flows that were studied in the apparatus. Figure 1 presents the model's lateral and plan view along with some main dimensions in centimeters, the inflow and outflow points are also indicated.

The apparatus was built in Plexiglas panels (10 mm-thick) to allow for flow visualization. The scale model reproduces all the key geometric features present in the actual stormwater system. These include sharp 90-degree bends with cross-sectional area reduction, sudden drop sections and a highly unusual reduction of the cross-sectional area toward the downstream direction. The cross sectional area of section A was variable, but ranged from 0.255 m^2 to 0.0825 m^2. For sections B and C the cross sectional area was 0.0693 m^2; Section D cross sectional area was 0.033 m^2.



(a) Lateral view of the model



(b) Plan view of the model

Figure 1. Lateral and plan views and pressure transducers locations.

Piezoresistive pressure transmitters were installed at the specified points in the apparatus and their locations are presented in Figure 1. Pressure transducer 3 (PT3) is located at the ceiling of the geometric singularity between Sections A and B. Pressure transducer 6 (PT6) is located at the bottom of the model at the intermediate section. The pressure transducers (SITRON, model SP21) had a pressure range from -0.5 bar up to 0.5 bar (PT6) and from -0.2 bar up to 0.2 bar (PT3). All transducers have a 0.25% accuracy of the measurement range, natural frequency of 1000Hz and the electrical connection type is DIN 43650. The data acquisition frequency was 100Hz.

The inflow water supply system is composed by a constant head tank (volume of 5 m^3, 3.8m elevation in relation to the apparatus invert) and two inflow points. At the inflow point 1 there was an 85 mm gate valve, used to establish the initial steady condition trough a 85-mm OD PVC line. The inflow point 2 was responsible for the addition of a much large inflow through the rapid (2 seconds) maneuver of a 110 mm ball valve placed on a 110-mm OD PVC pipeline. Siemens electromagnetic flowmeters are installed in the pipes that connect the inflow points to the constant head tank, upstream the valves. The electromagnetic flowmeters model is SITRANS FM MAGFLO MAG 5100 W, DN80 and DN100, maximum measuring range of $10 ms^{-1}$ and the response time set was 0.1s (range of 0.1 – 30s).

An iPad Pro was used to record the experiments and was placed at the region of the singularity between Sections A and B.

2.2 Experimental procedure and conditions

The experimental procedure consists of the following steps:

- Establishment of the steady flow through the inflow point 1;
- The manual opening of the 110mm ball valve installed in the inflow point 2 starts the run. This step aims to represent the propagation of the transient flow front, associated with a rain event;
- The filling process consists of a filling front propagating from upstream to downstream, and then by a hydraulic jump (or bore) moving from downstream to upstream. The run finishes when the hydraulic jump (or bore) reaches the upstream end;

The downstream condition was the experimental variable tested. The orifices located at the downstream end allow the establishment of a wide range of outflow discharge conditions. The experiments presented in this study were accomplished considering $0.005 m^3 s^{-1}$ and $0,014\ m^3 s^{-1}$. The initial water level set is indicated in Figure , allowing air entrapment in Section B.

2.3 Data analysis methodology

The data analysis methodology was based on the following steps:

- Evaluation of previously edited video images in order to identify the hydraulic phenomena of interest;
- Evaluation of pressure data to identify patterns of pressure variation and to associate them with the hydraulic phenomena identified in the videos;
- Evaluation of the translational velocity of the air pockets using an application specially developed for this purpose.

In the context of this research, video images are a rich source of information. The celerity of the bore front, translational velocity of air pockets and air pockets volumes are examples of the information that may be extracted from video images. In order to perform such measurements on the images, an application was implemented using Java supported by OpenCV library. During the experiments, a region of known area was placed in the camera view to serve as a reference for later conversion of the pixel area to actual units. Thus, informing the area of the known region, the application can estimate the pixel area in the image in cm^2.

3 RESULTS AND DISCUSSION

The data collected during the experiments in the physical model allow the establishment of three sets of results: pressure oscillation due to the passage of air pockets by the geometric singularity, evaluation of translational velocity of the air pockets and evaluation of downstream effects.

3.1 Pressure oscillation due to the passage of air pockets by the geometric singularity

The careful analysis of the videos, combined with the evaluation of the pressure records, allowed the identification of a pressure oscillation pattern when the air pocket approaches and passes through the geometric singularity.

When the filling front reaches the region of the geometric singularity, the whole volume of air present downstream of this point is entrapped. The mechanisms involved in air entrapment are being investigated. Once entrapped, the air pocket moves in the upstream direction and reaches the geometric singularity. Once entrapped, the air pocket moves in the upstream direction and reaches the geometric singularity. The passage of the pocket through the abrupt step at the top of the model fragments the initial volume of air, whose front part continues to advance now in Section A. The air volume that remains in Section B forms a new pocket that advances in upstream direction and passes again by the step at the top of the model, restarting the fragmentation process.

The air pocket passage through the abrupt step at the top of the model causes pressure spikes felt by the pressure transducer PTAir03, such as those show in Figure 2. The pressure oscillations pointed in regions a, b and c (Figure 1) are shown in detail in Figure 3 (a), (b) and (c). The nearing and the passage of the air pockets through the geometrical singularity were very distinguishable in the video evaluation for these three pressure oscillations.

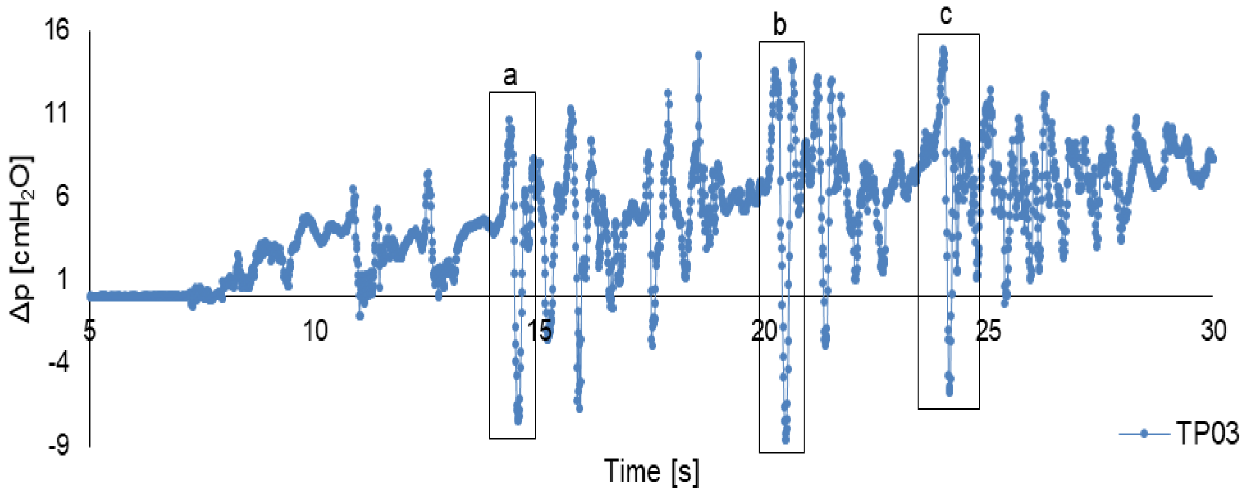
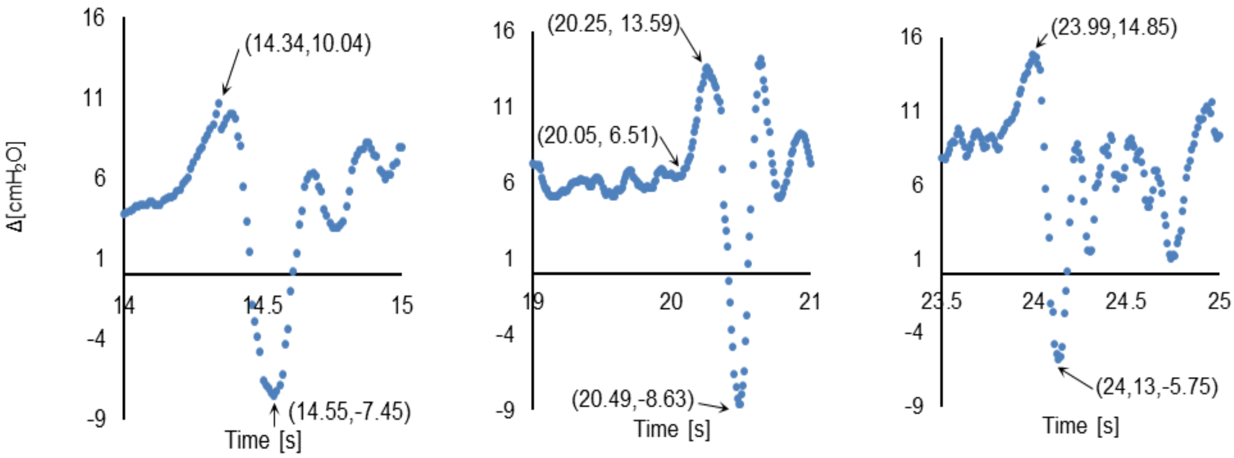


Figure 2. Pressure records indicating pressure oscillation due the passage of the air pocket through the geometrical singularity

The same pressure variation pattern is observed in Figure 3 (a), (b) and (c). Initially a slight increase in pressure and then a sharp negative decrease. The pressure oscillation that occurs between 20 and 21s, Region b, is well defined and therefore will be taken as an example of analysis. The temporal sequence of the images shown in Figure 4 presents the nearing and passage of the air pocket through the step on the top of the model that causes the pressure oscillation in Figure 3 (b).

The advance of the air pocket may be observed in Figure 4 (a) and (b). During this period, the pressure record indicates small variations in pressure (Figure 3 (b)). The pressure increases when the air pocket approaches the threshold of the step, from the moment 20.000s (Figure 4 (c), (d), (e) and (f)). Experiments currently being conducted on the model indicate that the movement of air pockets against the main flow direction causes local flow acceleration, resulting in a local increase of velocity. This effect is similar to the effects of a reduction of the cross-sectional area caused by a restriction. Thus, the effect of increasing the local velocity of the flow in the pressure transducer PTAir03 (this transducer is installed in the model against the direction of the flow) explains this slight increase of the pressure. The sharp decrease in pressure after the moment 20.25s results from the rise of the air pocket along the vertical wall of the step. The magnitude of this pressure decrease impresses, being 22.22cmH_2O. For the oscillations of regions a and c, this variation is about 17.49cmH_2O and 20.6 cmH_2O, respectively.

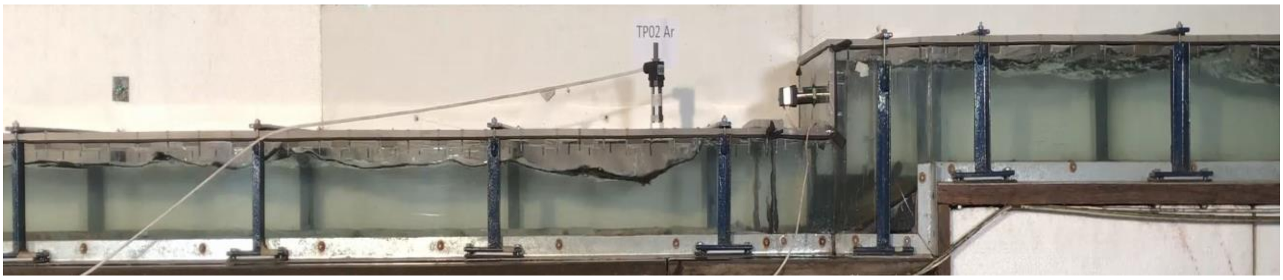


(a) Region a

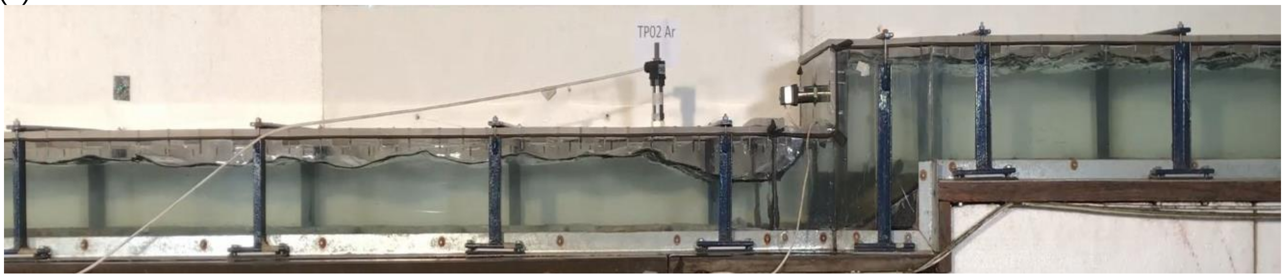
(a) Region b

(b) Region c

Figure 3. Details of three pressure oscillations caused by the passage of air pocket

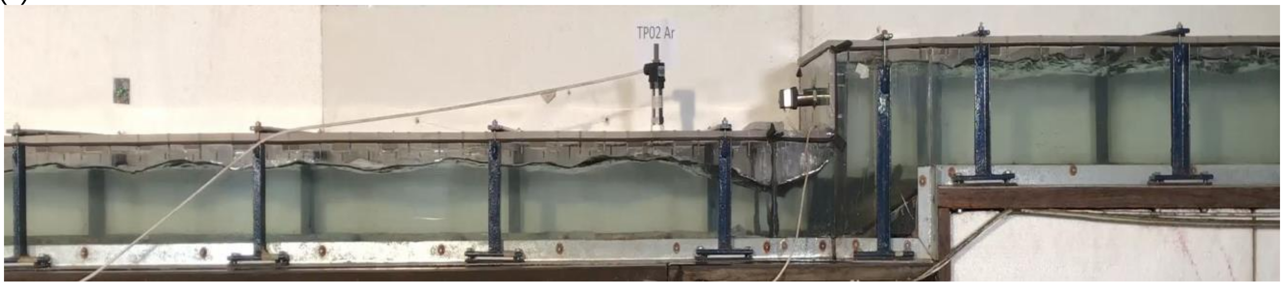


(a) 19.500s

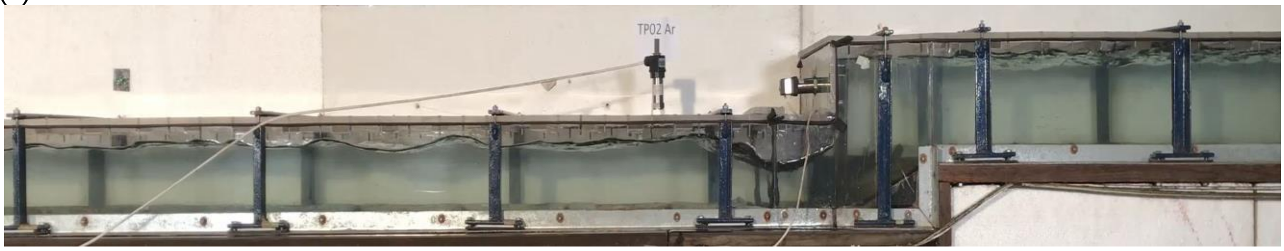


(b) 19.968s

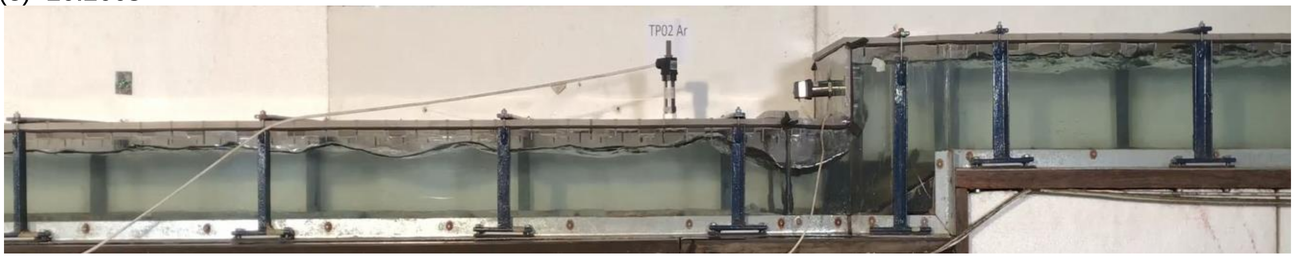
(c) 20.000s



(d) 20.101s



(e) 20.200s



(f) 20.230

(g) 20.270s

Figure 4. Advance and passage of the air pocket by the step at the top of the model.

3.2 Evaluation of translational velocity of the air pockets

3.3 Evaluation of downstream effects

4 CONCLUSIONS

If the formatter still needs to create a component which is not prescribed here, please incorporate applicable criteria that follow the styles provided (*e.g.*, spacing and typeface).

ACKNOWLEDGEMENTS

The writers would like to acknowledge the support of the CAPES, a Brazilian Government entity committed to the improvement of higher education personnel, which has provided a scholarship to support the PhD studies of the first author.

REFERENCES

.