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Advancing Forensic Flood Analysis Through Hydraulic Physical Models

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ABSTRACT

Urban density significantly increases the multi-hazard risks caused by extreme weather events. In Latin America and the Caribbean (LAC) countries, flood damages in urban areas are considerable and have shown a consistent annual increase. This challenge has prompted innovative educational responses to address the growing need for understanding and managing urban flood risks effectively. As part of postgraduate education efforts, the International Flood Initiative under the Intergovernmental Hydrological Programme of UNESCO for the LAC region (IFI-LAC IHP-UNESCO) aims to enhance understanding of vulnerability and flood risk estimation in urban settings. The initiative encourages the development of advanced hydro-informatic tools, watershed and river modeling techniques, and scale prototype construction to foster practical learning.

One of the educational approaches involves analyzing and reconstructing hydraulic infrastructure failures to provide insights into urban flood dynamics. This paper highlights the design and construction of a surface channel and a floodgate system equipped to enable controlled flash openings, capable of triggering crash waves. These facilities allow the recreation of three notable urban flood events, facilitating forensic hydraulic analysis. Detailed similitude analyses are provided, illustrating how sonic water level sensors can be effectively implemented and contributing to the understanding of flood risks and mitigation strategies in densely populated urban environments.

Keywords: *flood; forensic analysis; hydraulics; open channel; damage; disaster; flash flood; break wall*

INTRODUCTION

Physical models remain an optimal way to reproduce large-scale phenomena in hydraulics and hydrology. Although physical models (MF) have been built for more than 50 years, there is a general practice of using mathematical models to verify the veracity of the likeness with the real phenomena reproduced in the laboratory models (Choi et al., 2010; Jing et al., 2019). Hydraulic-works failures certainly represent a complex hydraulic problem to be modeled, and there may be multiple ways of reconstructing such a disaster. (Fraccarollo & Toro, 1995). It should be mentioned that the first physical models were sufficiently developed to faithfully recreate the local failure of the Malpasset dam in France, which caused severe economic damage (González-Cao et al., 2020; Valiani et al., 2002).

The significance of MF is underscored by a pivotal study published in 2008 by Abderrezzak et al. (2008). This study presented a comparative analysis between a physical hydraulic model and a two-dimensional numerical model for simulating the propagation of flash floods in urban areas and assessing the structural resistance of walls to these phenomena, which can result from excessive rainfall or dam breaches. The study's importance lies in its demonstration of good agreement with recorded data, particularly in urban settings. However, it is crucial to note that topography and the roughness coefficient are critical parameters for accurately simulating flood propagation, and some discrepancies arise due to the three-dimensional nature of flows around complex structure (Abderrezzak et al., 2008).

Despite these challenges, the use of MF offers a clear understanding of their advantages, as the phenomena can be observed directly at the relevant scale. This clarity reinforces the value of physical models in providing detailed and accurate representations of hydraulic events, thereby enhancing our ability to design effective flood mitigation and urban planning strategies.

Flash floods are phenomena that can affect both urban and rural areas. Their frequency is increasing due to climate change and the growth of human settlements. It is necessary to recognize that the increase in the frequency of extreme weather events, coupled with the inadequacy of hydraulic works to contain them, inevitably causes extensive damage and even loss of human lives.

A notable example is the flash flood that occurred in the Shimen Valley, China, in 2015, which resulted in nine fatalities. Field studies and numerical simulations systematically investigated the causes of the disaster (Ball et al., 2019). It was determined that an intense storm caused rapid

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runoff and high discharge rates due to steep catchment surfaces and channels. The flood transported not only a large volume of water but also rocks and debris, which accumulated in a narrow section of the valley, forming a debris dam. The failure of this debris dam generated a wave that rapidly propagated to the mouth of the valley, sweeping away several walls and, tragically, people along with them. This study underscores the importance of understanding the triggering factors of flash floods to develop effective preventive measures, especially in vulnerable mountainous areas.

In urban areas, the possible failure of storm drainage works could increase the water level rapidly, causing damage inside the houses (Liu et al., 2018). The Latin America and the Caribbean (LAC) regions are by nature an exposed area to extreme events. Floods, tropical storms and hurricanes have become more and more frequently near large cities, increasing the vulnerability of communities. These critical phenomena have become serious risks and, unfortunately, damage to property and loss of human life are regrettably unavoidable. Most seriously, they cause a major backward step in the social development of the countries of the LAC region (Gutierrez-Lopez & Aparicio, 2020). In a framework of international cooperation and promotion of science, it is urgent to consolidate capacities in the LAC region through scientific collaboration with research centers. The mutual exchange of knowledge, projects and experience in the field of water resources enhances a vital activity in a region that has three of the poorest countries in the world.

With respect to the construction of hydraulic models and prototypes, the LAC region is at a disadvantage with respect to developed countries. The provision of economic resources is essential for the laboratories' construction and equipment, which are decisive in the development of science. In this aspect, promoting the low-cost building, upgrading and equipping of physical models are an essential activity in the region. Knowing the flow patterns in MF civil engineers are able to design optimal hydraulic works, for example, are able to sufficiently protect urban centers (Dehdar-Behbahani & Parsaie, 2016). One of the most dangerous components is without doubt the flow velocity. It has been proved that flash-floods are becoming more and more frequent. High water velocity could affect the integrity of almost any structure and cause its eventual collapse. Two recent cases highlight the importance to study flow velocity. The first is the velocity overload on the energy dissipater in the Chenderoh Basin, which was carried out by numerical and physical model analysis (Zaki et al., 2019). The second, the construction of the physical model of the Malana-II hydroelectric dam spillway, which was fundamental in order not to affect the safety of this dam (Ahmad, 2018). In this way, MF can strongly contribute to the knowledge of high flows velocity; however, the benefit of these MFs is enriched if we recognize forensic hydraulics as a discipline that allows us to learn from disasters. Therefore, MF, that can reconstruct a catastrophic event in a controlled manner, could undoubtedly contribute to the learning of failure mechanisms and to the knowledge of disaster reconstruction.

Hence, the purpose of this work is to demonstrate the potential of a sudden flood to affect urban structures (retaining walls) using a scaled physical model (MF) of the phenomenon. This involves a channel and a floodgate, which were enabled to operate jointly and trigger a crash wave from a height of 40 cm, similar to Lobovský et al. (2014). All hydraulic similarity calculations are presented to simulate the failure of a typical urban brick wall. This is equivalent to collapsing a 12 cm thick red brick wall with a height of 48 cm inside the channel.

Using the prototype channel, reconstruction and forensic analysis of the damage caused to a building in a specific residential area can be carried out. A brick wall was affected by a flow of water. Using speed, time and flow, with the scaling process, an effective force of Fp=20.23 kN provided by a flow equivalent to 82.5 m^3/s was determined. To successfully replicate the phenomenon on a larger scale, in an estimated time of 8.43 seconds.

The aim of this study is to demonstrate the potential of physical hydraulic models (MF) in simulating and analyzing the impact of sudden flood events on urban infrastructure, with a particular focus on the failure mechanisms of retaining walls. This research employs a scaled model that triggers a crash wave to replicate real-world flash-flood conditions. The study aims to contribute to the advancement of hydraulic research and forensic analysis by showcasing the potential of low-cost, scalable models in flood-prone regions, offering valuable insights for improving flood mitigation and infrastructure resilience.

METHODOLOGY

Design and construction of the channel

The controlled experiments were carried out at the local facilities of the Hydraulics Laboratory of the Water Research Center of the Autonomous University of Queretaro. The model area has five open channels with adequate characteristics, in terms of dimensions and flow, for this type of experiment. The canal has a width of 1.47 meters, a total length of 10.38 meters and a height of 0.755 meters, with a slope of 2%, which is considered the minimum slope to reduce water flooding (Figure 1-a). There are two centrifugal pumps in the laboratory installation, which supply and regulate the continuous flow of water through the model. The functional specifications corresponding to each of them are presented suite:

a) Pump #1: model 14744198-100 and series 4 01 14744198-9001 k 0005, provides a nominal efficiency of 90.2%, minimum efficiency of 88.5%. Vertical 215 TP frame motor with type F insulated motor with maximum allowable temperature of 155°C. Weight 99.88 kg.
b) Pump #2: serial 54469118, works at 1500 RPM, three-phase at 220 or 440 volts. Vertical frame motor 215 TP, TP with insulation type F with maximum admitted temperature of 155°C.

The purpose of this equipment is only to supply the volume of water required for the stream rate needed in the channel; when the storage is complete, they stop working therefore that only the behavior of the hydrostatic pressure generated by the flow volume has an influence. However, prior to carrying out the tests, the effective facilities were adapted due to the need to cause the effect of a flash water flow, which consisted of modifying the gate that would allow retaining the 0.4 m of water flow.

Once the water storage was filled to the required level to be able to carry out a sudden flood, human force was used to lift it abruptly, causing the water depth to be released with sufficient speed and force to replicate the phenomenon of flooding. hit against the brick wall (Figure 1-b).

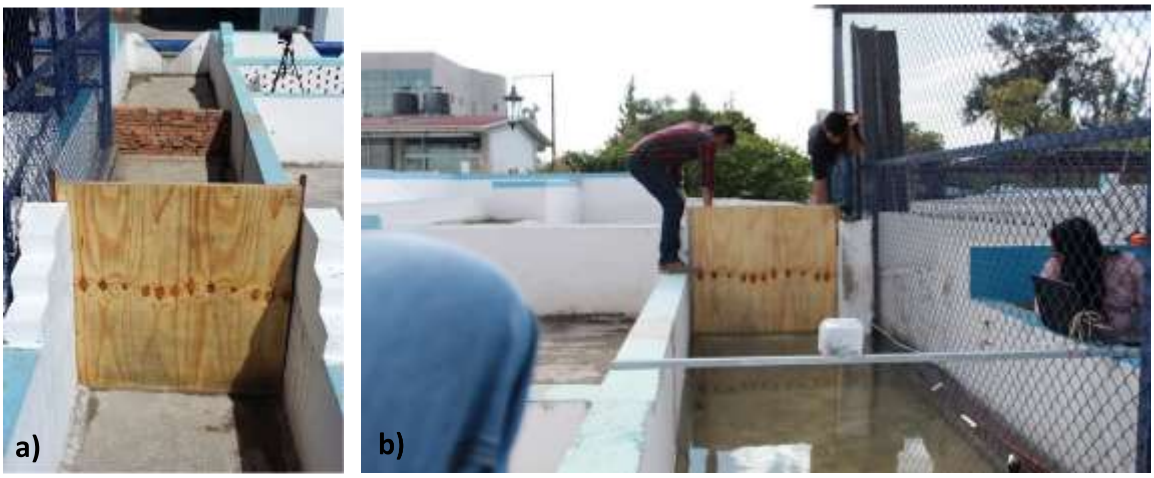

Figure 1 a) General view of the channel, tank storage area and flow-gate, b) Physical model operation

This modification allows for having an inflow of 61.3 l/s. In addition, the hydrostatic pressure generated to the bottom of the gate can be received through the static pressure model, getting a value of 400 kg/m^2, which if one takes into account by considering the channel width, the mass of 82 kg is obtained. Since this mass comes from an unsteady state, the velocity with which it strikes the wall is 0.4526 m/s and the time elapsed during this phenomenon is 2.8 seconds. Thus, it is possible to estimate the acceleration it causes and therefore get the force necessary to collapse the wall.

This corresponds to 41.19 N necessary to affect a wall or any other type of structure. To support the scaling calculations, a contention wall is built to which the indicated force will be engaged. In order to evaluate the displacement effect of the wall. Each of the blocks was placed in the same way to maintain the sliding action of this type of material due to the consequence of the flash flow (figure 2).

It is evident that the force generated by water flow during a flash flood (FF) may not be sufficient to cause the collapse of a brick wall bonded with mortar. This is due to the relatively low volume of water and the limited impact force against the structure. The strength of a brick wall with mortar is significantly influenced by the cohesion provided by the mortar, which enhances the stability and resistance of the assembly against external forces such as water flow.

In this context, it has been decided to conduct an experiment using brick blocks without any adhesive between them. The absence of mortar will allow for better observation of the direct effects of water flow on each individual block. This experimental approach is essential for understanding the dynamics of block distribution and movement during and after the flash flood event. By eliminating the variable of mortar, a clearer insight can be obtained into how water influences the position and displacement of the blocks.

The primary objective of this approach is twofold: first, to observe the movement patterns of the blocks when they are directly exposed to water flow without the additional stabilization provided by mortar; and second, to analyze the redistribution of the blocks post-flood to better understand the forces involved and the potential structural consequences in real-world scenarios where mortar may have degraded or be absent. This knowledge can be crucial for the design of flood-resistant structures and for planning mitigation measures in areas prone to FF.

Figure 2 Detail of the channel and preparation of the brick wall to induce failure

It should be noted that the joining of the bricks of the wall does not have any linking material, since carrying out this type of process would increase the scaling factor of the strength of the work to values above the proper values in a similar prototype work.

Hydraulic scales of the channel

Experimental channel, as hydraulic models of physical characteristics, present simplified systems of engineering works. This will be a success much easier to make observations and control mechanisms and conditions. According to the characteristics of the models, they can be classified as follows:

a) With respect to their geometrical similarity.

b) With respect to the degree of contour deformability and stability.

However, the main focus is on geometric matching, implying the reduced physical models must be similar to the prototype. By direct analogy, with the hydraulics of physical scale models "two or more hydraulic systems are similar if they fulfill the conditions of geometric, kinematic and dynamic similarity at the same time", with a given level of pre-adopted physical scale model approximation (Yang et al., 2010; Hu et al., 2020). Geometric similarity implies that a relationship between dimensions of the model and the prototype is the same. They are geometrically similar if all those dimensions that compose them in each direction of the axes are related by means of the same length scale.

$$E_L = \frac{Lp}{Lm} \qquad \text{..........................(1)}$$

Where:

Lp : length of the prototype

Lm : equivalent length of the model

E_L : the length scale

Kinematic similarity exists in the motions of the model and the prototype if related particles arrive at analogous points at similar times. Therefore, the model and the prototype are forced to be linear, temporal and thus velocity scales.

$$Ev = \frac{vp}{vm} \qquad \text{.......................(2)}$$

$$ET = \frac{Tp}{Tm} \qquad \text{.......................(3)}$$

Where:

Ev : velocity scale

ET : time scale

Since there is a scale of velocities and times, it is fulfilled that there is a scale of accelerations.

$$Ea = \frac{ap}{am} = \frac{E_v}{E_t} \qquad \text{..........................(4)}$$

Where:

E_a : acceleration scale
ap : prototype acceleration
am : model acceleration
E_v : speed scale
E_t : time scale.

Therefore, if the scaling values corresponding to time, velocity and acceleration are understood, all these variables can be known at equivalent points of the prototype. Considering also the dynamic similarity, if these forces are exerted by the fluid at corresponding points of the prototype and model, by means of the existence of a fixed scale value of forces, it is said that this similarity is fulfilled. The fact that such dynamic correspondence is present implies the two previous ones also exist. The forces on the particle are examined by means of a polygon, which must be geometrically similar and remain a constant factor. This group of forces exerted on the particles of the fluid is composed of:

- Force due to friction
- Surface tension force
- Gravity force or specific weight
- Inertia force

If the sum of all the component forces plus the inertia force is not equal to zero, the particle would accelerate. In the same way it can be shown that if it is equal to zero, the particle is in equilibrium:

$$Fg + Fp + F\upsilon + F\delta + EL^2 + FI = 0 \qquad \text{......(5)}$$

$$Fg = mg = \rho L^3 g \qquad \text{......(6)}$$

$$Fp = (\Delta p)A = (\Delta p)L^2 \qquad \text{......(7)}$$

$$Fv = \mu\left(\frac{dv}{dy}\right)A = \mu vL \qquad \text{......(8)}$$

$$F\sigma = \sigma L \qquad \text{......(9)}$$

$$FI = ma = \rho L^2 v^2 \qquad \text{...(10)}$$

Where:

m : mass of the body of water
g : the Gravity acceleration ρ : fluid density
L : length
p : pressure difference
A : area
μ : dynamic viscosity
σ : surface tension
a : acceleration
dv/dy : transverse gradient of velocities
v : velocity
E : elasticity variable

The dynamic similarity implies all the scaling of the forces is equal. The ratios between the forces caused in the equations are used to define the most relevant dimensional parameters in the domain of hydraulics, retaining that:

$$EF = \frac{Fgp}{Fgm} = \frac{Fpp}{Fpm} = \frac{Fvp}{Fvm} = \frac{FIp}{FIm} = \frac{F\sigma p}{F\sigma m} \qquad \text{..(11)}$$

It is important to mention that the dimensionless characteristics of the fluids, as follows: (i) Reynolds number, (ii) Froude number and (iii) Euler number. They present the similar relation of data from the model and prototype. However, what is attempted is the reproduction of a physical phenomenon in identical geometric sections to scale, what is expected is that the dimensional characteristics are exactly the same and the relation of scales is unitary. However, in a rectangular channel, with a flow around the critical or super-critical flow, high Reynolds number values, higher than 10000 in the model, are present in all sections and therefore this means that:

$$E_{Nr} = \frac{E_v E_L}{E_\mu} = E_v E_L > 1 \qquad \text{..................(12)}$$

Where:

E_{Nr} = Reynolds Number Scale
E_v = Velocity Scale
E_L = Length Scale
E_μ = Dynamic Viscosity Scale

Since the viscosity ratio is unitary, due to the fact that water flows in the prototype and the model, as well as the ratio of velocities and lengths is equally greater than one. That is why the Reynolds number at a given point in the prototype will always be greater than that of the model at the same point. The ratios of velocities, time and flow rate used are given by the following given expressions (Liu et al., 2018; Sánchez Quijano et al., 2018):

$$E_v = \sqrt{E_L} \qquad \text{.................(13)}$$

$$E_T = \sqrt{E_L} \qquad \text{.................(14)}$$

$$E_Q = E_L^{\frac{5}{2}} \qquad \text{.................(15)}$$

Where:

E_v : velocity scale

E_T : time scale

E_Q : flow scale

E_L : length scale

Channel instrumentation

For the equipment of the channel, an ultrasonic sensor was built to measure data in real time. The HC-SR04 sensor was used for this purpose (figure 3). It is based on the emission of ultrasonic pulses and measures the time taken by the sound to reach a receiver. The sensor sends short ultrasonic pulses of at least 20 kHz; these pulses are reflected on the surface of water. The speed of the sound is constant and by knowing the time it takes for the sound to reach the receiver, the water flow in the channel is calculated. In addition, this sensor offers high precision detection, stable sensing and its operation is unaffected by sunlight or dark objects.

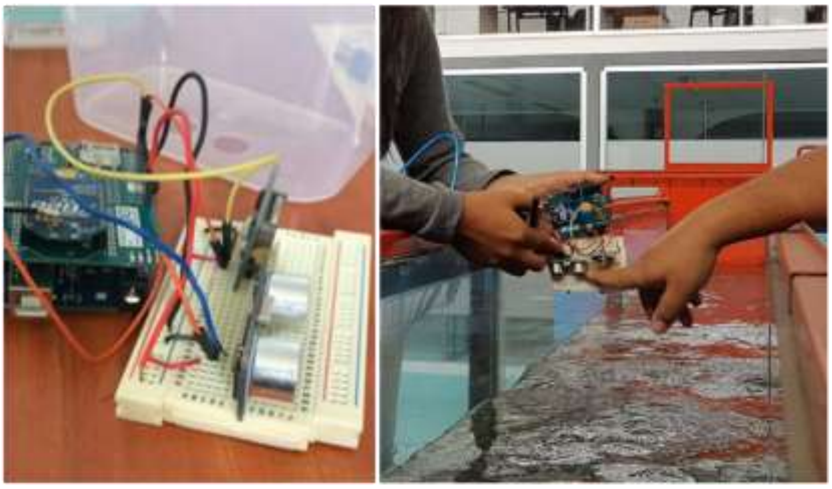

Figure 3 Connection and calibration details of the Arduino type ultrasonic sensor

RESULT AND DISCUSSION

Hydraulic and kinematic scaling of the model

The selection of the horizontal and vertical linear scales is carried out in an independent mode. Considering that the model should habitually be as large as possible. Now of operating the model, the scale effect should be as reduced as possible, to minimize the loss of the large-scale simulation of the phenomenon. According to the table of standard line-scales, for hydraulic models of structure dynamics under wave action, we have:

i. In two dimensions: from 1:20 to 1:60

ii. In three dimensions: from 1:40 to 1:80

Apply to models without fixed depth disturbance., in this sense without modifying the flow inlet depth. The recommended size is 1:30. The dimensions in Table 1 refer to the total longitude of the channel (elevation E) and the height of the floodwall (elevation C) (Figure 4). Since the recommended scale applicable to models without fixed bottom distortion is 1:30. The estimated lengths of the prototype will be thirty times the distances of the model (Figure 5). Table 1 shows the comparative values of both magnitudes, in the most relevant dimensions.

Table 1 Main channel dimensions

Profile view (m)			Plan view (m)		
High	Model length	Prototype length	High	Model length	Prototype length
Distance between fault wall and gate	0.755	22.65	Wall width	0.155	4.65
Length	10.38	311.4	Width	1.765	52.95

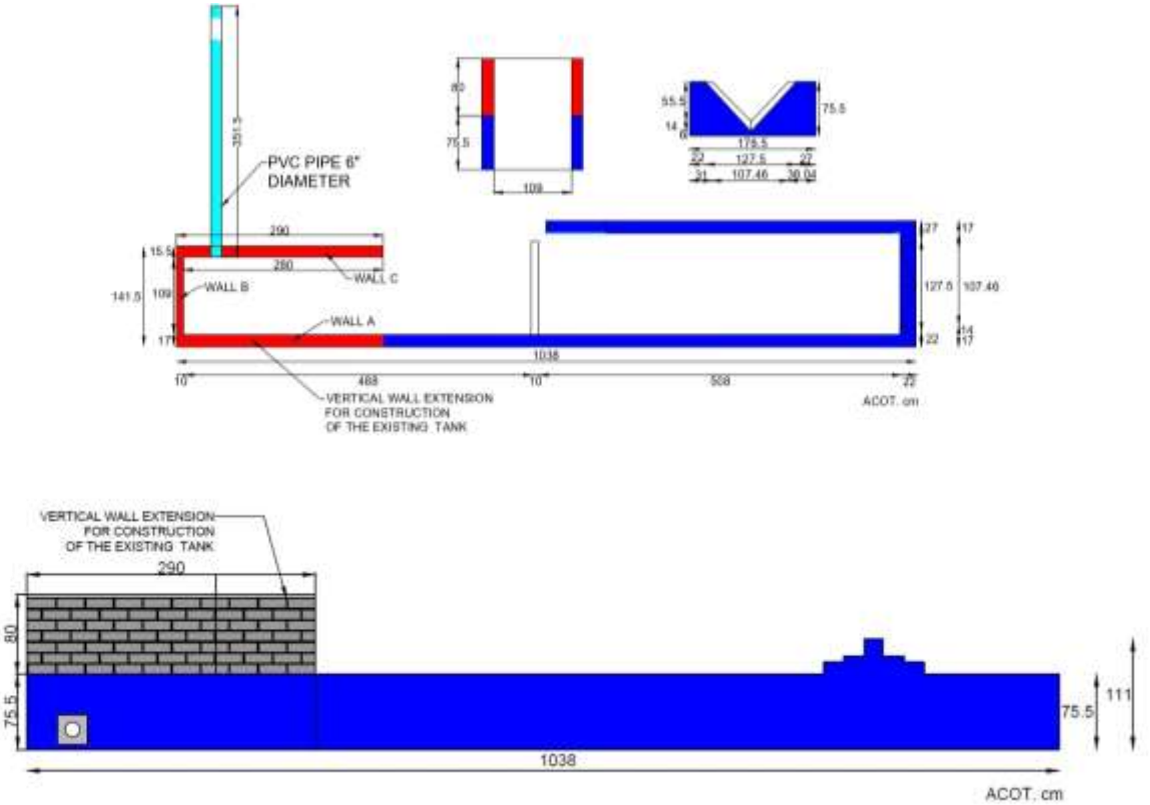

Figure 4 Dimensions of the main channel, plan and cross section

Figure 5 Perspective and plan view of the channel

Hydraulic and kinematic scaling of flow wave effects

The MF was built to know the characteristics of the stream response in the channel. The operation and measurements carried out in the channel provided detailed information on the damage caused by flash flow in the affected area. By means of the dynamic similarity and the equations mentioned above, a Froude number value equivalent to 2.11 is obtained, which means a supercritical flow. The existing unitary ratio allows the calculation of the magnitudes series that characterize the phenomenon as flash flow. The force of the water necessary to collapse the bricks-wall in a time of 2.8 s in the model is equivalent to

41.18 Newtons. It is important to remark that this value was obtained with the water level of 0.4 meter and with the same bricks placement for the creation of the wall. On the other hand, if the water flow is increased, the material used for the wall is different, the roughness provided by the channel covering is changed, or the way in which the bricks were arranged; another result should be expected.

The calculation was proposed using hydrostatic load, also known as fluid pressure, which is exerted within the gate wall. When this wall is abruptly opened, a velocity and flow rate of the fluid are generated. This dynamic is considered fundamental to understanding the behavior of the system under analysis, as the sudden release of pressure induces a significant flow that can be measured and modeled to obtain precise and predictable results. The methodology employed is based on previously mentioned principles of fluid mechanics, which allow for the calculation of both the escape velocity of the fluid and the flow rate, as well as the resulting Reynolds number, from the variation in initial pressure.

Using velocity, time and flow-rate, with the same methodology, an effective force of Fp=1,112.48 KN provided by a flow-rate equivalent to 302.17 m^3/s being obtained for the prototype. To successfully replicate the phenomenon at a larger scale, in an estimated time of 15.33 seconds.

Simulation of structure rupture

Given the hydraulic and kinematic characteristics of the flow and with the floodgate in place, it is possible to replicate a failure whose displacement and debris drag exceeds two meters in length in the model. Applying dynamic-geometric scaling, it is equivalent to a debris drag of 60 m (Figure 6). This figure proves an induced failure of a brickwork wall that simulates a wall in an urban area. The destruction of the wall and the propagation of the debris make it possible to recreate the failure. The scene is complemented with the help of sonic sensors and videos taken in slow motion. The sensors allow us to know the water levels and consequently the energy with which the water hit the wall. It is significant to mention that this channel has already caused several failures of walls, dam and hydraulic works in this canal. It is also controlled by the opening of the floodgate provided it is a flash flow or if the failure is the result of a controlled discharge.

Application case: storm of June 13-14, 2014

In the State of Querétaro, in central Mexico, the Water Research Center (CIAQ) operates 40 AWS stations distributed throughout the State. These stations transmit every five minutes in the dry season and every minute in the rainy season (June to October). This database includes records from June 2012 to May 2020 (Gutierrez-Lopez, 2021). Records of more than 550 severe storms have been monitored by the RedCIAQ alert system, which is a signal type and operates throughout the State. 148.220.4.26/app/earlyWarning/cepcq/lluvia/ It is the basin of the Querétaro River (12 km2) that runs through the metropolitan sector, which includes the largest coverage area. In recent years, the intensity of precipitation has increased dramatically. Table 2 shows some intensity values at some AWS stations within the metropolitan area. These records have already been the subject of study, especially the contrasting storms of two consecutive years (2013 and 2014).

Then, ten times greater rainfall intensities can be observed, especially in the summer months. These storms caused severe flooding and damage in the urban area of the city of Querétaro. Specifically the storm that occurred on the afternoon of June 13, 2018 and continued during the early hours of the 14th; It was notably torrential. On June 13 the storm began at noon. The greatest intensity gap began at 5:15 p.m. with an intensity of 90 mm/h. At 17:18 the storm had its highest intensity with 108 mm/h and after this time the storm continued until 17:27 with an average intensity of 70 mm/h. This storm caused severe damage in several neighborhoods in the city of Querétaro. Using conventional hydrology methodology, the reconstruction and forensic analysis of the damage caused to a building in the Milenio III residential complex can be carried out. A brick wall was hit by a jet of water (Figure 7). Using speed, time and flow, considering the conventional hydrology methodology in conjunction with the equations determined in this paper, an effective force of Fp=20.23 KN was obtained provided by a flow equivalent to 82.5 m^3/s. Successfully replicate the phenomenon on a larger scale, in an estimated time of 8.43 seconds.

Figure 6 Result of an induced failure in the channel

Table 2 Rainfall intensity of storms already studied. Adapted from Gutierrez-Lopez et al., (2019)

ID Station	Date	Rainfall (mm/h)
Centro-H	06/12/2013	21.8
Centro-H	07/06/2013	15.3
Centro-H	09/15/2013	17.3
Centro-H	11/19/2013	25.3
Centro-H	06/20/2014	26.7
Milenio	06/13/2018	108
Chulavista	08/18/2014	108
Candiles	08/18/2014	150
Cimatario	08/18/2014	108
Centro-H	08/18/2014	96
San Jose Alto	08/18/2014	180
Viñedos	08/18/2014	96

Figure 7 Failure of the brick wall during the storm 13-14 June 2018 and successful reconstruction of wall failure in forensic analysis channel.

CONCLUSIONS

The recent modification of the model area in the hydraulics laboratory of the Faculty of Engineering at UAQ, alongside the proper installation of a specialized channel for forensic analysis of flash-flow, has proven to be a notable and successful advancement. This innovation has enabled the precise recreation of various failures associated with rapid flows over hydraulic and urban infrastructures, providing a deep understanding of the mechanisms and consequences of such events.

The experimental channel has demonstrated its value by accurately replicating conditions that have led to the failure of hydraulic works and other critical infrastructures, offering valuable information for forensic analysis. This precise recreation capability is not only a technical achievement but also has significant practical implications. There is a growing interest in utilizing this channel to investigate and reconstruct failures in civil works, which can significantly influence preventive risk determination and responsibility assessment.

This channel, unique in its kind in Mexico, represents a significant advancement in the field of hydraulics in the country. Its existence not only marks a milestone in the capacity for research and prevention of future damage caused by failures in hydraulic works but also places Mexico in a prominent position in international hydraulic research.

Beyond its application in forensic analysis, this channel has become an invaluable educational tool. It is currently used in the preparation of postgraduate courses in the field of environmental hydrological criminalistics, providing students with practical, hands-on experience in the recreation and analysis of flash-flow events. This not only enriches the academic curriculum but also prepares future professionals with crucial skills and knowledge to address the environmental and infrastructure challenges of the 21st century.

In conclusion, the implementation and use of the experimental channel for flash-flow forensic analysis in the hydraulics laboratory have opened new frontiers in hydraulic research and education in Mexico. This advancement not only facilitates a deeper understanding of failures in critical infrastructures but also offers a powerful tool for training experts in environmental hydrological criminalistics. With this channel, Mexico positions itself as a pioneer in the research and prevention of hydraulic failures due to flash flows, significantly contributing to the welfare and safety of infrastructures and communities.

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