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Analysis of the stormwater drainage of the historic walls of Cartagena de Indias between the bastions of San Lucas, Santa Catalina and Santa Clara

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Abstract. The city walls of Cartagena between the Baluarte of San Lucas and Santa Clara reflects the consequences of poor stormwater drainage. In the present investigation the current drainage state of this area have been evaluated, assessing its sizing and conditions to be then modelled through SWMM 5 software for return periods of 5, 10, 15 and 20 years respectively. Finally, it has been determined that the physical deterioration of the drainage elements justifies the malfunction of the whole system, therefore cleaning and periodic maintenance of the drainage elements is strongly suggested.

1. Introduction

Batteries, fortifications, defensive walls, forts and fortified ports are common in the list of world heritage of America, and the fortifications of Latin America and the Caribbean are not stranger to it. At the present time, all these scenarios are cultural expressions of the same continent, therefore protect and preserve theme it is of the extreme importance [1]. Some fortifications have a high degree of authenticity in terms of location and configuration, shapes and designs, materials and constituents, however, they are generally subjected to severe tropical climates (including tropical storms and hurricanes), which may threaten the authenticity of the property, as in the case of the fortifications of Old Havana [2]. Among the most significant monuments there are undoubtedly the walls of Cartagena [3-6], World Heritage Sites according to UNESCO since 1984, whose purpose was to protect the City from the wartime continuous attacks [7], which are nowadays seriously deteriorated according to research done in the matter [8].

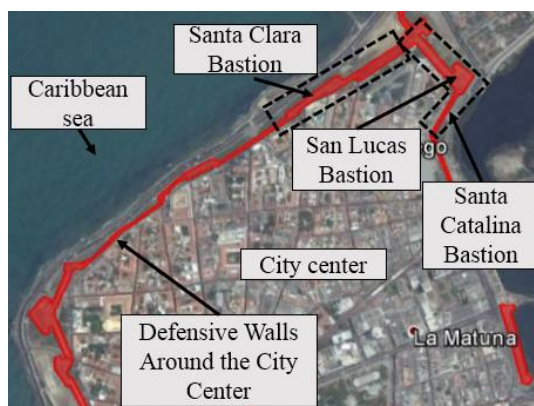


Figure 1. Area and bastions of interest.



Water is one of the factors that have a greater incidence in the process of deterioration of this type of fortifications, since its passage attrition causes erosion, furthermore the infiltration of water in the pores and micropores of the stones, reacts with the stone materials of the wall generating as end products substances vulnerable to be dragged by wind or overflow, in addition to vegetation and plants that in the growth process of its roots expand the joints between the elements of the wall. Being the walls extensive in its totality, the sector of the bastion of San Lucas, Santa Catalina and Santa Clara have been chosen as part of the study (Figure 1). A characterization of the pluvial drains of the mentioned sector was made, and a hydraulic simulation and a description of the problematic is presented [9].

2. Methodology

2.1 Field work

In the field work a study of the interested area was made, and the typologies of drainage were identified on which the rainwater is evacuated in the structure. In addition, dimensions, afferent areas and conditions of each drainage were defined.

2.2 Calculation of drainages hydraulic capacity

After obtaining all the field data, the hydraulic modelling has been done, using the Uniform Flow Method to calculate the flow rate of each drainage element, Horton's Method [10] for infiltration control and the Rational Method for calculating the runoff rate have been chosen; Manning's coefficient of permeability and coefficient values were obtained from the Technical Regulation of Drinking Water and Basic Sanitation of Colombia (RAS 2000) [11], according to the characteristics of each drainage element.

Precipitation data were obtained from the Rafael Núñez station of the city of Cartagena defined in the Master Plan of Pluvial Drainage [12]. Using the software SWMM 5, the different objects were created in the plane of the study area, like drainage sub-basins of the system and the afferent area of each drainage element, and the different properties of the same were fixed. Then initial and final points of each conduit were added, called nodes, and later the conduits were joined with the nodes.

Subsequently, through the rain icon, the time series of data, the value of precipitation in millimetres and the time intervals of these precipitations were defined (Figure 2, model of the channel 1).

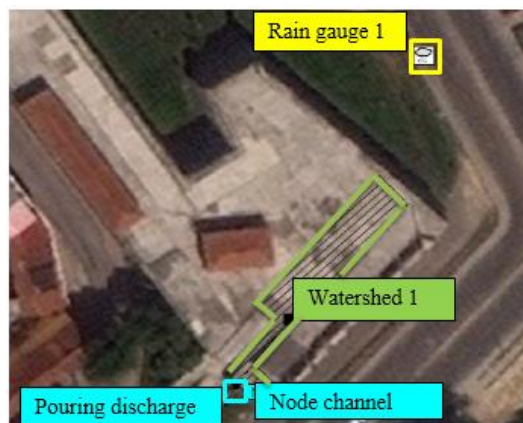


Figure 2. Channel 1 modelling.

With all the aforementioned data, the flow rate that hydraulically works in each drainage element was calculated. At the hydrological level, for each drainage element was evaluated the flow rate of runoff that must support for the return periods of 5, 10, 15 and 20 years.

3. Discussions and results

For the initial diagnosis of the pluvial drainages of the study area, the elements were classified by typology (Figure 3).

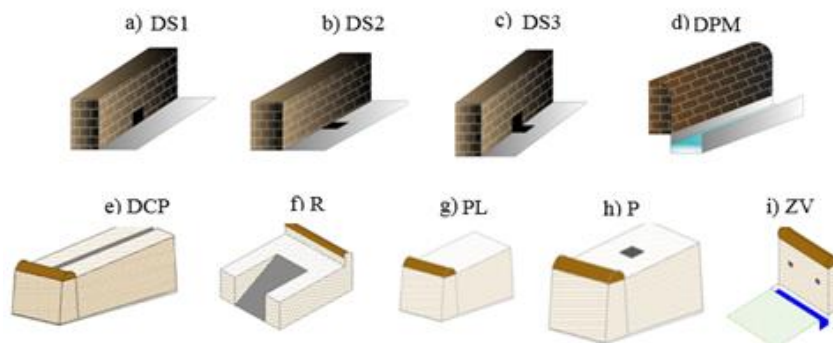


Figure 3. Drainage elements, adapted from [8].

Each of them is described below:

- DS1 – Drainage of Parapet: channels located at the top of the wall, to evacuate rainwater falling on the embankment, its opening is in the parapet;
- DS2 - Platform Drainage: channels located at the top of the wall, to evacuate rainwater falling on the embankment, its opening is on the platform;
- DS3 - Combined Drainage: channels located at the top of the wall, to evacuate rainwater falling on the embankment, they have an opening in the platform and in the parapet;
- DPM - Wall Foot Drainage: rectangular channels located at the bottom of the wall, more precisely at the foot of the wall, they collect rainwater draining from their afferent areas (green areas, road, etc.) and of the upper drains (DS1, DS2, DS3);
- DCP - Drainage Platform Channel: channels of rectangular form located in the embankment; (DS1, DS2, DS3), or to other continuous DCPs. In order to achieve this, it is necessary to conduct the water from its concentration points to another type of drainage (DS1, DS2, DS3);
- R - Ramp: inclined structures that start in the upper embankment of the walls and end in the ground floor of the same. They allow a part of the rainwater that falls on the embankment to drain into the drainage of the Historic Centre of the city;
- PL - Embankment: the upper platforms or platforms of each of the stretches of the walls. It could be said that it is the element with which the rainy waters make their first contact. The rain waters that precipitate on it, are transported by means of slopes towards the DS1, DS2, DS3, DCP or Ramps;
- P - Rainwater Well or Reservoir: rectangular holes located on the platform of the wall panels, it is believed that these holes had the function of storing rainwater in the past;
- ZV-Green Zones: These are areas with vegetation, located in front of the cliffs or contraescarpas of the walls. The rainwater that precipitates them is evacuated towards the MPD.

Once the drains of the structure were numbered and catalogued, traditional distances, slopes and areas were measured for each individual drainage. In general, the rainwater drainage of the walled cordon between the bastions of San Lucas, Santa Catalina and Santa Clara of the city of Cartagena is constituted by a total of eighty-six (86 channels), most of all DS1, DS2 and DS3, of which are normally operating 16% (14 channels), partially operating 28% (24 channels) and non-functional 56% (48 channels).

Particularly the ramps of the sector of the San Lucas bastion are physically deteriorated, with many cracks and presence of vegetation, the reason for this condition could be the lack of periodic maintenance of these structures, nevertheless its slope allows to evacuate raining waters coming from a part of the embankment of that section. As well the ramps of the sector of the Santa Catalina Basin and Santa Clara

have good conditions and their slopes allow to efficiently evacuate the water evacuating them to the drainage of the Historic Centre. The flow data is digitized in Table 1.

Table 1. Hydraulic calculations of the most representative channels.

Dimension	DS1 n°1	DS1 n°12	DS2 n°31	DS3 n°61
Canal elevation (m)	0.190	0.210	0.100	0.175
Canal base (m)	0.120	0.090	0.120	0.170
Canal grade	0.020	0.020	0.021	0.495
Manning Coefficient	0.016	0.016	0.016	0.016
Caudal (l s ⁻¹)	25.72	18.56	11.88	39.04

Runoff flow results according to the return period (Table 2):

Table 2. Runoff flow according to the return period of the most representative channels.

Return period (years)	Flow DS1 n°1 (l s ⁻¹)	Flow DS1 n°12 (l s ⁻¹)	Flow DS2 n°31 (l s ⁻¹)	Flow DS3 n°61 (l s ⁻¹)
5	6.432	3.195	0.990	0.683
10	7.287	3.617	1.122	0.774
15	7.838	3.890	1.207	0.833
20	8.255	4.097	1.271	0.877

On the other hand, the hydraulic flows obtained in each drainage element do not exceed the total capacity of these elements, however the presence of external factors such as solid residues, vegetation and/or sediments that interrupt the route of rainwater precipitating in the sector studied, before reaching their final disposal point, preventing the normal operation of most drainage elements. For the green areas, have been found that permeability is very low and penetration of water is irrelevant. Consequently, according to the results obtained by the SWIMM 5 for the different return periods of 5, 10, 15 and 20 years, almost none of the channels are flooded, with the exception of two of them.

According to the height of the water sheet inside the critical elements, 87% of these do not exceed the height of the channel, which represents the maximum height of the water level. In terms of flow velocities, have been found that the vast majority of the modelled channels exceeded the parameter of the minimum speed established by the Basic Water and Sanitation Regulation RAS, mentioned above, whose value is 0.75m s⁻¹.

4. Conclusions

In the analysis of all the drainage elements modelled, none of the channels show flooding for the return periods of 5, 10, 15 and 20 years, with the exception of two of them because their cross-sectional dimensions are relatively smaller compared to the other drainage elements. According to the height of the water sheet inside the shaped elements, only 13% of these exceeds the height of the channel, which means that those elements work under pressure and increase the cross-sectional area would be necessary.

The main causes of malfunction found were: lack of maintenance and internal collapses due to degradation of the same wall material, presence of vegetation and solid residues, accumulated sediments, corrosion, inverted slopes and specifically in the wall foot drains (DPM) were observed to have

obstructed outlets, consequently the water remains stagnant causing foul odors and proliferation of vectors and microorganisms.

A campaign of revision and cleaning as well as enlargement of the undersized channels is suggested, in order to allow the structure to evacuate the water properly, safeguarding its lifetime and its historicity.

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