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# Unused Raft Foundation Spaces as Detention Ponds to Mitigate Urban Flooding

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## Abstract

Urbanization is changing the original catchment properties which are altering the urban hydrology. With increased impermeable pavements, including buildings and roads leading to less infiltration and more runoff during precipitation comes with the upsurge in urban flooding frequency. To mitigate urban flooding, onsite source control measures integrated with existing drainage systems are widely used. The onsite source control is aimed to increase the ability of infiltration and detention to decrease and delay the surface runoff. In addition to building a new structure, the existing and unused raft foundations in buildings can be utilized to detain excess runoff. This study investigated 4 buildings in Taipei City, Taiwan, and found that raft foundations show high potential as an onsite detention method. The legislated minimum water detention is 0.078 m<sup>3</sup> per square meter of the construction area (m<sup>2</sup>); however, the average of 0.23 m<sup>3</sup>/m<sup>2</sup> can be achieved when an unused raft foundation is employed. Under this possible scenario, the flood mitigation capacity of Taipei city can be increased from 78.8 mm/hr to 82.0 mm/hr.

## Introduction

Urban development is slowly reshaping the hydrological cycle by altering vegetation, land cover, and topography. Changing these factors without proper management will significantly affect the ways water move through the environment. Impervious surfaces that come with rapid urban development accelerate runoffs to receiving water bodies inducing faster and higher peak flows, coupled with unpredictable rainfall frequency from global warming resulting in a rise in urban flooding. To mitigate the impacts of urban flooding, the low impact development (LID) in the US, sustainable drainage system (SuDS) in the UK, water-sensitive city in Australia and New Zealand are established [1-3]. In these methods, increasing onsite infiltration and storage are the main measures to reduce extra runoff. However, in addition to the nature-based solutions

(NBS) [4], the existing raft foundation of buildings can also serve as an alternative measure to detain and store extra runoff.

Taipei city is the capital city of Taiwan and is a highly-dense area. However, Taipei has seen a continuous rise in flooding frequency over the past 10 years. The current Taipei storm drain standard of handling design storm is 78.8 mm/hour. However, from 2011-2021 storms exceeding the capability of the storm drain occurred every year and resulted in urban flooding (Figure 1). To reduce the runoff from construction, a legislated water detention rate in Taipei city was set, which is 0.078 cubic meter (m<sup>3</sup>) runoff per square meter (m<sup>2</sup>) of the construction site should be retained on-site and refrained from discharging into the storm drain. The legislated water detention rate is calculated from the following equation:



$$\text{Minimum On-Site detention Capacity (m}^3\text{)} = \text{Site area (m}^2\text{)} * 0.078 \text{ m}^3/\text{m}^2$$

(Figure 1)

Taipei is heavily dominated by high rises with raft foundations due to the raft foundation’s ability to provide a watertight construction underneath the foundational level above the groundwater table and act both as a water prevention retaining wall and a basement wall. The area of the raft foundation which sits above the foundational level and below the basement level is interconnected by ground beams which creates vacant space between the vertical and horizontal ground beams called pits. As the pits are typically empty, architects begin to design specific functions for the pits to fulfill different bylaws and regulations. Therefore, this study is aimed to seek a new function for these pits in raft foundations to combat urban flooding. Storm runoffs within the foundational pit of the raft foundation prevent overloading the existing storm drain

thereby minimizing flood risk and damages.

**Methods**

Four cases in Taipei city were assessed to understand how the current on-site detention is applied and how much vacant pit capacity is available to be employed as on-site detention. The descriptions of the cases are summarized in Table 1. The current detention pit volume is the existing volume used to detain runoff, in accordance with the required detention rate, 0.078 m<sup>3</sup>/m<sup>2</sup>. Pit spaces within the raft foundation are comprised of firefighting basin, rainwater recycling pond, sewage treatment facilities, and water seepage pond. The total pit volume deducting the current detention volume and other required volume is the extra potential detention capacity. Therefore, the maximum detention pit capacity is the current detention volume plus the potential volume and the potential detention capacity ratio is the maximum volume divided by the total site area (Table 1) (Figures 2, 3).

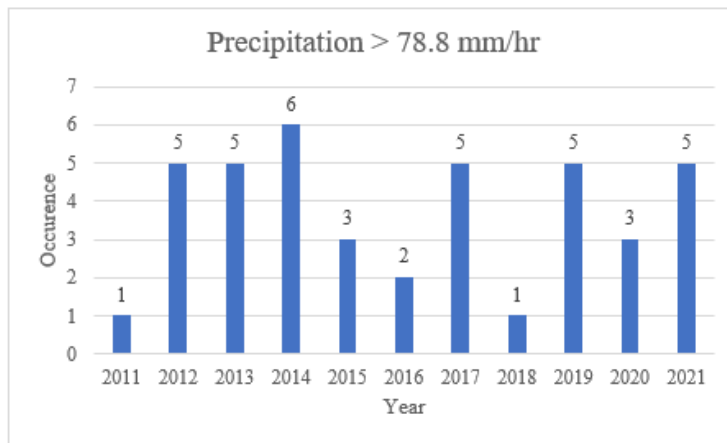
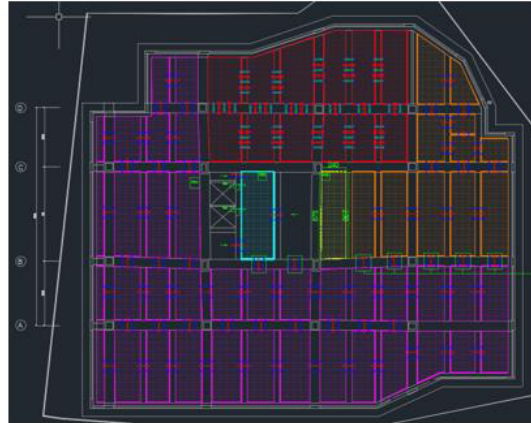


Figure 1: 2011-2021 Precipitation over 78.8 mm/hr in Taipei City.



Figure 2: The Zhongxiao E. Rd development block. (Own Work).



**Figure 3:** The pit allocation of Zhongxiao E. Rd. case. Total pit volume: 1,235 m<sup>3</sup>, purple & orange pit (on-site detention & water recycling pit): 730 m<sup>3</sup>, orange pit (water recycling pit): 223 m<sup>3</sup>, red pit (firefighting reservoir): 200 m<sup>3</sup>, yellow pit (sewage treatment facility): 38 m<sup>3</sup>, and teal pit (water seepage storage): 44 m<sup>3</sup>.

**Table 1:** Basic data of the studied cases and the detention ratio.

| Location of the Cases | Site Area (M <sup>2</sup> ) | Total Pit Volume (M <sup>3</sup> ) | Current Detention Pit Volume (M <sup>3</sup> ) (All Larger to the Regulated Volume) | Potential Detention Capacity (M <sup>3</sup> ) (Total Volume Minus Other Regulated Volumes) | Maximum Detention Pit Capacity (M <sup>3</sup> ) (Current Detention Pit Capacity (M <sup>3</sup> ) + Potential Capacity (M <sup>3</sup> )) | Potential Detention Capacity Ratio (Maximum Detention Pit Capacity (M <sup>3</sup> ) / Site Area (M <sup>2</sup> )) |
|-----------------------|-----------------------------|------------------------------------|---|---|--|---|
| Dechang St            | 714                         | 319                                | 73  | 69  | 142  | 0.2   |
| Zhongxiao E. Rd       | 2,152                       | 1,235                              | 730   | 0   | 730  | 0.34  |
| Dunhua S. Rd          | 504                         | 233                                | 40  | 97  | 137  | 0.27  |
| Jianguo N Rd          | 524                         | 222                                | 41  | 11  | 52   | 0.1   |
| Average               | 973.5                       | 502.25                             | 221   | 44.25   | 265.25   | 0.23  |

To illustrate our method, we took one of the projects listed above as an example below.

The Zhongxiao E. Rd. site's area is 2,152 m<sup>2</sup> and the area of the whole block including the outer yellow dash which denotes the center of the street has an area of 5,648 m<sup>2</sup> (Figure 2). The total current detention capacity is 730 m<sup>3</sup>. Based on the regulated detention volume, which is 2,151 m<sup>2</sup>\*0.078 m<sup>3</sup>/m<sup>2</sup>=168 m<sup>3</sup>, the current detention volume meets the legislation standard. The Figure 3 is to visualize the proportion of different usages for the foundational pit in the diaphragm/slurry wall technique in Taiwan.

This project utilizes the Taipei City's incentive standard for Urban Renewal Planning and Design which specify if the development has double the capacity of regulated minimum on-site detention the development can be awarded an additional 1% of total floor space. Doubling the minimum on-site detention capacity is 168 m<sup>3</sup> \* 2 = 336 m<sup>3</sup>. In this project, the construction company utilized the whole 730 m<sup>3</sup> as detention capacity in applying for the incentive policy. So that there is no extra volume for potential detention capacity.

## Findings

As Taipei implemented the minimum on-site detention regu-

lation in October of 2013 and with approximate 2.5-3 years construction period, we can safely assume projects from 2017 onwards will all have minimum on-site detention. From the table below, the annual new construction area in Taipei city was shown. Under the regulated detention ratio, a total of 4,048,850 m<sup>3</sup> detention capacity were provided in the 5 years to detain rainwater. When applying the suggested ratio, an additional 5,652,222 m<sup>3</sup> capacity could be provided. This implied that close to 3 times the volume can be used for rainwater detention in the building's raft foundations compared to the current state (Table 2).

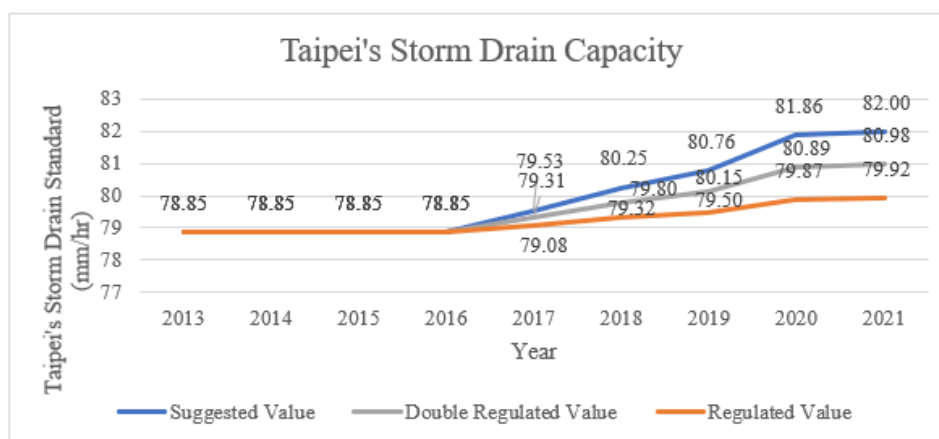
**Table 2:** Comparison of the new suggested detention ratio and Taipei City's current regulated ratio.

| Year | Total Annual New Construction Area (M <sup>2</sup> ) | Regulated Ratio Capacity (M <sup>3</sup> ) (Ratio:0.078 M <sup>3</sup> /M <sup>2</sup> ) | Suggested Ratio Capacity (M <sup>3</sup> ) (Ratio:0.23 M <sup>3</sup> /M <sup>2</sup> ) | Additional Capacity (M <sup>3</sup> ) *Suggested Capacity- Regulated Capacity |
|------|--|--|---|---|
| 2017 | 7,982,456  | 622,632  | 1,835,965   | 1,213,333   |
| 2018 | 8,558,348  | 667,551  | 1,968,420   | 1,300,869   |
| 2019 | 6,085,973  | 474,706  | 1,399,774   | 925,068   |

|       |            |           |            |           |
|-------|------------|-----------|------------|-----------|
| 2020  | 12,980,812 | 1,012,503 | 2,985,587  | 1,973,083 |
| 2021  | 1,578,085  | 123,091   | 362,960    | 239,869   |
| Total | 51,908,332 | 4,048,850 | 11,938,916 | 5,652,222 |

Assuming the additional capacity is evenly distributed within Taipei city, the additional capacity divided by the total area of Taipei city can give us an approximate depth for absorbing additional storm runoff. This means that the additional detention capacity provided by the raft foundation could help to soak up rainfall and

enhance the current flood mitigation ability. Figure 4 shows that the transformation from additional detention volume to rainfall intensity, and the accumulative volume in 2021 could provide an additional 3 mm incremental rainfall depth ability (Figure 4).



**Figure 4:** The potential extra storm drain capacity provided by raft foundation detention in Taipei city.

## Conclusion

This research shows by increasing the current minimum on-site detention capacity with unused raft foundation is possible. Current projects show that doubling to tripling the current Taipei's standard for minimum on-site detention is feasible thus instead of building a new detention facility, fully utilizing the vacant foundational pits of buildings for potential detention capacity could be an alternative measure in reducing urban flood risks.

## Acknowledgment

None.

## Conflict of Interest

No conflict of interest.

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