Rainwater storage tank as a remedy for a local urban flood control

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Abstract

Surcharge runoff over the capacity of drainage pipes is one of main flood breaking factors in urban area. Change into larger pipes is costly and time consuming solution. Rainwater tanks can be a sustainable solution for the control of heavy runoff.

The Rainfall-Storage-Drain (RSD) model is developed for the design of rainwater tanks of flood control. Design rainfall of Huff’s distribution and runoff analysis on building rooftop makes inflow curves into the tanks. Through a water balance equation, tank volume versus peak flow curves can determine the minimum tank volume needed for controlled peak flow value of a design period. The case study in Seoul City shows a tank of 29 L/㎡ can control the runoff of 30-years with the drainage pipes of 10-years design period. The RSD model can give simple and easy curves to understand for tank capacity determination in a local flood condition.

Keywords: urban flood, rainwater management, rainwater tank, RSD model, decentralized system

1. Study background and goals

1.1 Flooding in Seoul

In cities all over the world, the characteristics of floods are changing markedly because of increasing urbanization and climate change. Figure 1 shows the drainage districts of the metropolitan area of Seoul in 2001. The Seoul storm sewerage consists of 16 districts, 13 of which were inundated by the flood of 2001. Among these, three had problems of overflow in the final receiving water channel or as a result of their topographical condition, and the remaining nine districts were flooded by runoff in excess of the maximum capacity of their storm sewerage (Seoul, 2002).
Because only one or two storm sewers overflowed in the nine districts with inadequate drainage capacity, increasing the size of the sewers using conventional engineering techniques was the only solution proposed. This option is very costly and will take a long time to complete, because Seoul is a high-density city with heavy traffic and complex industrial activities. Furthermore, a larger sewer of fixed capacity may not be enough for heavier rainfall in the future (Kim, 2006).

1.2 Review on urban flood control studies

(1) Review on decentralized management studies
Decentralized and localized management of water is an innovative strategy developed in recent years. Localized and integrated flood management was studied and modeled at the watershed scale by R. H. McCuen (McCuen, 1974). He concluded that a regional approach to stormwater could reduce peak runoff while “individual-site” approaches could result in flood increases. Low-impact development strategies (LID) were introduced in a manual by the county of Prince George County in 1999 (Prince George’s County, 1999). In LID, urban stormwater can be controlled through a variety of methods of detention and retention instead of the conventional end-of-pipe or in-the-pipe strategies.

In Korea, Kim and coworkers pointed out the need for development of a new drainage control system for surcharge runoff control that takes account of the unique condition of small confined areas (Choi et al, 2001; Shin et al, 2005; Kim, 2005). Recently, Miyazaki pointed out that an on-site, decentralized rainwater detention system using a lot of tanks was effective in control of the flow in urban drain pipes. Engineering planning methods are necessary to decide the location of each tank and its capacity (Miyazaki, 2006).

During recent years, decentralized and integrated water management has developed into a remarkable strategy for sustainable and safe urban infrastructure. Sophisticated scientific and engineering methodologies are required to implement the system.

(2) Review on rainwater tank design
The design of rainwater tanks follows the same principles as conventional detention tank design in storm sewerage. McCarthy proposed that the water balance equation could be applicable in the design of water detention tanks (McCarthy, 1938). Recently, Guo developed a modified design method for flood control detention tank volume (Guo, 1999, 2001).

However, the design of rainwater tanks for capture and storage of water is not easy in the sophisticated routing method for detention tanks. The classical and simple water balance equation was developed for rainwater tank design. Hermann and Schmida calculated the flood control effect of a rainwater tank as its volume varies (Hermann and Schmida, 2000). Vaes and Berlamont analyzed the effect of rainwater tanks on storm sewerage design in Belgium (Vaes et al, 2001). They concluded that detention in existing rainwater tanks can control a peak runoff flow of 5-year frequency.

Mooyoung Han published a study on rainwater tank volume determination under Korean rainfall conditions (Han et al, 2004). Mun showed that decentralized small rainwater tanks could be more effective in control of floods than one large tank, using SWMM modeling analysis in an apartment house complex (Mun et al. 2005).
Many studies conclude that numerous small tanks can reduce urban flooding and reduce inundation of the inner city. Nevertheless, rainwater tanks continue to be designed only as a private water supply facility.

This study analyzed the urban flood control effect of a rainwater tank system. The RSD model was developed to analyze tank capacity and the peak runoff flow. Furthermore, the RSD model can calculate the minimum tank volume to control a hypothetical design storm of any duration.

2. Introduction of the RSD system
The RSD system is a roof runoff control system using rainwater tanks (Figure 2). The RSD system consists of rainfall, storage and drainage processes. During rainfall, the rooftop of a building catches the water and collects it into a rainwater tank, thereby controlling the flow. Flow over the tank storage capacity goes through the storage process directly into the urban drain system.

![Figure 2. The RSD rainwater management system](image)

The RSD model is a new numerical model for the analysis and design of each process in the RSD system. This study develops the RSD model and shows a case study of RSD for Seoul City.

3. Methodology of RSD model development
The design of a facility for flow control must follow a detailed and reasonable design that considers the local rainfall conditions. In this study, the RSD model is a tool for calculating the variation of outflow from storage with different tank sizes and rainfall conditions.

3.1 Precipitation and runoff analysis in the rainfall process
The rainfall process analyzes the rainfall conditions and runoff from building rooftop catchments. The rainwater tank controls the runoff by accumulating flow from the roof, similar to the operational conditions of conventional drain control basins in present urban drainage systems. Thus, the design rainfall curves for a conventional basin can be used in the RSD model. Huff’s distribution and the Yen & Chow method are reasonable for design
rainfall analysis for Korean metrological conditions (MOCT, 2000). This study draws design rainfall curves on the 2nd-quartile, 50% rainfall cumulative curve of Korean Huff curves. This pattern and probability is proposed for the design of most work for hydrological facilities by Huff (Huff, 1967). Return periods of 10-year, 20-year and 30-year rainfall curves of Seoul are analyzed for the following case study of rainfall tank design. Figure 3 shows the design rainfall curves for a 10-year-frequency storm in the Seoul City area.

![Design rainfall curves of 10-year frequency](image)

Figure 3. Design rainfall curves of 10-year-frequency in the Seoul city area

Rainfall on a catchment surface causes runoff to flow from the area into the rainwater tanks. The inflow into the tank is one of the governmental conditions on the tank design. The quantity of water collected during the rainfall process is controlled by the surface and the structural design condition of the building’s roof. The conditions of rooftop surface design were studied with respect to runoff from the rainfall events of the design curves. Figure 4 shows the detailed factors of the rooftop. Table 1 shows the structural conditions for the roof drain and the assumptions for the simple runoff formula of the RSD model.

![Scheme of runoff during rainfall](image)

Figure 4. Scheme of runoff during rainfall
Table 1. Factors and assumptions for runoff analysis

<table>
<thead>
<tr>
<th>Factors</th>
<th>Field conditions</th>
<th>Notes and assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment area</td>
<td>0.1~0.3 ha</td>
<td>Minimum limit for conventional models = 1.3 ha</td>
</tr>
<tr>
<td>Material</td>
<td>Impervious material, i.e., concrete or waterproof sealing</td>
<td></td>
</tr>
<tr>
<td>Drain condition</td>
<td>Architectural design for rapid and complete drainage</td>
<td>inflow from rainfall = runoff flow Time for concentration = 0 No depression storage</td>
</tr>
<tr>
<td>Flow time</td>
<td>Design for short time flow</td>
<td></td>
</tr>
<tr>
<td>Depression storage</td>
<td>0.5~0.1 inch (ASCE, 1992)</td>
<td></td>
</tr>
<tr>
<td>Runoff formula</td>
<td>Q(t): runoff flow = I(t) : intensity per unit time × A: catchment area</td>
<td></td>
</tr>
</tbody>
</table>

This study developed a simple equation for runoff curves from rooftops during rainfall. Conventional hydrological runoff models can be applied to larger areas, over 1.3 ha (Ponce, 1989). A rooftop area is generally about only 0.1~0.3 ha. The rooftop is an artificial surface designed to drain rapidly and completely. The assumptions in Table 1 should be reasonable for the conditions of rooftops. They are the same as the conditions for ideal runoff surface in Mulvaney’s equation, meaning that the runoff flow is the same as the rainfall quantity (Huggins et al., 1982). The runoff curves have the same pattern as the original rainfall event. The calculated runoff curves were synchronized with monitored curves in their pattern and peak breaking points in a field study of the rainwater system of SNU (Kim, 2006).

3.2 Tank capacity design in the storage process

The storage process needs an analytical method for determining the peak values that vary with tank capacities. Figure 5 is a scheme of a simple rainwater tank structure and its water flow. In this system, a water balance equation can calculate the flow variation against tank capacities.

Figure 5. Structure and water flow of a simple rainwater tank

\[
V_{t_e} = \int_{t_0}^{t_e} (Q_{in} - Q_{out} - Q_{sup})dt
\]

Equation 1 is the water balance equation for the system of Figure 5. Q_{in} is the inflow quantity to the rainwater tank, the same as the runoff from the roof. Q_{out} is the overflow
from the tank into the urban drainage. $Q_{sup}$, the water flow of supply water to the building, can be assumed to be zero because the water demand during a rainfall event would be random and small, having no relation to the rainfall event.

Figure 6. Tank capacity vs peak outflow curves for 10 years in Seoul City

Figure 6 shows the tank storage capacity versus the maximum outflow value curves of 10-year rainfall events in Seoul. The unit of tank capacity is expressed as catchment depth; that is, tank volume ($m^3$) per unit catchment area ($m^2$). The deep black dotted line shows the maximum peak outflow values following tank volumes, which is the general tank storage capacity vs maximum outflow curve for a 10-year-frequency storm in Seoul city. Although only three rainfall times are shown in Figure 6, events of many other durations and intensities are possible.

4. Case study of RSD model in Seoul

Figure 7 shows the tank volume versus peak outflow curves for 10-, 20- and 30-year-frequency rainfall events according to the method of Figure 6. On the curves, the minimum necessary tank volumes to peak outflow values can be found.

Figure 7. Tank volumes vs peak overflows as rainfall frequencies in Seoul
As an example of the tank design from Figure 7, Table 2 shows the analysis of the runoff control effect of a 29 L/m² rainwater tank.

Table 2. Runoff control effect analysis of 29L/m² tank in Seoul from Figure 7

<table>
<thead>
<tr>
<th>Rainfall frequency (year)</th>
<th>W/O tank</th>
<th>W/ tank of 29L/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak runoff flow (m³/5min/m²)</td>
<td>Peak frequency</td>
</tr>
<tr>
<td></td>
<td>Peak frequency</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.22</td>
<td>10 year</td>
</tr>
<tr>
<td>20</td>
<td>0.26</td>
<td>20 year</td>
</tr>
<tr>
<td>30</td>
<td>0.28</td>
<td>30 year</td>
</tr>
</tbody>
</table>

In the case of the RSD system with a tank of 29 L/m² in Seoul, the rooftop peak runoff for a 10- or 20-year-frequency rainfall event can be controlled. The RSD system could control the peak outflow of the 10 year rainfall event using only about 70% of the capacity. Additionally, the 30-year peak flow can be reduced to almost the same value as a 10-year-frequency rainfall event. This means that an RSD system with a storage tank of 29 L/m² capacity can control the runoff of a 30-year rainfall event from a unit catchment area with a drainage pipe designed for a 10-year rainfall event.

5. Conclusion and discussion

In this study, the rainwater tank system for runoff management was designed using the RSD model to manage heavier rainfall runoff without changing the existing urban drainage system. The present urban flood problem can be solved by engineered rainwater tanks without the lengthy and costly operation to increase the capacity of the storm sewerage. The RSD model can be a simple and practical design method for rainwater tanks for field engineers who are not accustomed to the RSD system.

Effective flood control in flood-prone districts needs a harmonious system of decentralized rainwater management that can be realized by scientific planning and decision-making tools. Rainwater tanks can be located in optimum positions for the best control. The RSD model can be developed into an integrated engineering model for the planning and design of decentralized rainwater management systems.

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