Drainage Simulation of Detention Pond with Tidal Effect at the Outfall during a Storm Period

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Abstract: - Due to the occurrence of typhoons each year, the island of Taiwan often suffers a flooding problem during the storm period particularly at the urban low-lying areas. In this study, the storm water management model was employed to develop a drainage model for a specified region in the largest harbor city Kaohsiung, Taiwan. An actual typhoon case and four different design rainfall recurrence periods including 5, 20, 50, and 100 years were used as the input conditions in the drainage model. More importantly, the tidal level effect at the outfall of drainage system was considered to check the flood drainage control process for a proposed detention pond. The analyzed results showed that the variation of tidal level at the outlet of drainage system do have a significant influence on the efficiency of flood drainage. Furthermore, the installation of a detention pond could effectively control the floodwater drainage at the urban low-lying area during the storm period. The simulated results might provide useful information for relevant engineering applications in a place with similar regional characteristics to the present studied case.

Key-Words: - Typhoon, urban low-lying land, detention pond, tidal effect, flooding area, drainage simulation

1. Introduction
The recent world news reported that the hurricane Katrina that occurred on August 29th, 2005, caused tremendous flood damages in the city of New Orleans at Louisiana state, USA. A further influence on the rising of oil price may have shaken the growth of world economics, and the resulting flood control problem may have bothered many of people working in this area. Similarly from history records, the typhoons often raided the island of Taiwan each year. As on July 11th, 2001, typhoon Tanmei caused huge flood damage which covered more than 300 hectares of low-lying lands in Kaohsiung, the largest harbor city located in southern part of Taiwan [1]. This incident not only endangered the public lives and properties, but also reflects the importance of flood control problem for urban low-lying lands, particularly with the effect of tidal level variation at a specified region.

There are many factors to affect the operation of a drainage system in the urban area, and the consideration of drainage problem may cover various aspects including hydraulic analysis, economical evaluation, engineering design and maintenance [2-4]. Due to the limitation of an existing drainage system in Kaohsiung city, the main drainage line cross-section is unable to expand its size to rapidly transport the runoff into the downstream area. Actually, this conventional concept may cause a burden and increase the possibility of flood damage at downstream region of the watershed. Therefore, in order to improve the efficiency of flood drainage system, the installation of a detention reservoir at the urban low-lying area becomes an applicable way, which may help to reduce the runoff and delay the arrival time of peak discharge for decreasing possible flood damage.

The efficiency of using a detention pond can be found in many previously published literatures [5-11]. However, this research assumed that the runoff enters the pond instantly, and took the initial rainfall time as the datum for calculation in the flood hydrograph. In other words, these previous studies were focused on the detention pond problem at a hillside, which is somewhat different from a drainage problem at an urban area. Still, the research results did prove that the use of a detention pond may delay the arrival time of a flood peak discharge, so that the same principle may be applied to a drainage system at the urban low-lying region.

Hence in the present study, the commonly used Storm Water Management Model (SWMM) developed by Environment Protection Agency (EPA) of the United States [12], is taken to build a drainage model for the Benher village including a natural lake Jinshi in Kaohsiung city. An actual recorded rainfall information due to typhoon Tanmei, and four different recurrence periods including 5, 20, 50, and 100
years of the design rainfall, are taken as the input conditions. Furthermore, the effect of tidal level variation at the outfall of drainage system is considered in the model to simulate the flood drainage control process for the proposed detention pond in the study area. The analyzed results may help check the performance of the existing drainage system, and may provide useful information for relevant engineering applications in the specified urban low-lying region.

2. Model Construction
The island of Taiwan has an area of 36 thousands square kilometers, where only 1/3 of the area is flat land. The total population is 23 million, so that there is a very high population density, especially in the metropolitan areas with a limitation of available land resource for construction. As seen in Figure 1 is the vicinity of Kaohsiung City, the largest harbor city in Taiwan, where the sketch of research area suffered a serious flood problem. Based on the topographical map, this research area covers a range about 240 hectares including a natural lake Jinshi and a proposed detention pond Benher.

In Figure 2, the existing drainage system shows that there are two external inflows coming from Kaohsiung County, those result in a total of 439 hectares for the watershed area. In this region, the sub-channels E, F, G, H, I, and J collect the floodwater and merge to the main drainage channel K during the storm period. Then, the floodwater goes to the outfall Ai-River, and finally it goes through the harbor to the open sea of Taiwan strait.

To understand the efficiency of drainage system during a storm period, the SWMM package is taken for constructing a model to simulate drainage problem in the present specified research area. As the choice of a suitable input rainfall pattern is very important in the simulation model, and there are several methods that can be used for designing rainfall. But the most reasonable way is to adopt the long term statistical information collected from local rainfall stations. Thus, according to the available flood prevention and drainage report for Kaohsiung city [1], a rainfall intensity formula for different recurrence periods and a rainfall percentage distribution of 2-hour duration are employed in this study to obtain the input design rainfall.

Then, in order to facilitate the calculation of the entire drainage system, it is necessary to divide the watershed area into several sub-catchments. The present research area is divided into 83 sub-catchments, and the detailed information including area, width, percentage of impervious area, depth of depression storage, slope, percentage of non-depression storage area, and Manning parameter, are well arranged for each sub-catchment. Besides, the drainage system is mainly composed by two objects (i.e. node and link), so it is required to transfer the actual rainwater drain information to the nodes and the links.

The total 84 nodes are numbered in accordance with the object function such as manhole, pump, divider, and outfall. Meanwhile, the data such as section dimension, length, slope, and Manning parameter are important for the total 83 links and must be arranged properly. Finally, a drainage model is constructed and the model
details of lake Jinshi and detention pond Benher are shown in Figure 3 (a) and (b), respectively.
For lake Jinshi, the effective area of water storage is about 9 hectares, and the effective depth is 0.85m, which results in a flood detention capacity of 765,000m³. During the storm period, once the flood discharge is more than 13.5cms, this lake will take over to adjust the extra water, but when the lake water level reaches to 7.9m, a release of floodwater is then acted to make sure the ability of flood prevention. In this natural detention lake, two storage units and five orifices are used to control the efficiency of drainage properly.

For detention pond Benher, the total design flood detention volume is about 98,724m³ and the allowable depth is 6.45m. In this proposed detention pond, the main facilities include 3 storage units, 3 orifices, and 2 sets of pumps. The mechanism of these facilities will start operating in accordance with the water level at the key point (see Figure 3(b)). The key point is chosen at the main drainage line, and the design critical depth is 4.32m. With this design information, the drainage model is ready for further investigation at the specified research area, and the results are shown in the following sections.

3. Model Verification
Once the simulation model is developed for a specified drainage system, it is better to check its suitability by using the actual storm information and the observation record. However, in the present investigation area, it is difficult to make a comparison because there is neither a record station nor a water level observation along the drainage lines. Alternatively, an available reported regional

Figure 3. Drainage model (a) at lake Jinshi (up), (b) at detention pond Benher (down).
The flooding area during a storm period may be taken to compare with simulation result. This approach may not be used to verify the simulation result very precisely, but it at least provides a way to check the drainage model for the specified case study.

By inputting the actual measured averaging rainfall distribution due to typhoon Tanmei (11/07/2001), and by setting the actual water level of the Ai-River in simulation model, the calculated drainage result for the research area is displayed in Figure 4. From the distribution of flooding area for the simulated result and the actual report, it can be found that the major flooding area is about at the same location for both cases, whereas the actual report covers a wide range including nodes K3-1 and K3-2. Based on the geographical relation, these two nodes have a slightly higher elevation than that of the downstream nodes. But they are still at a relatively low-lying area, and thus the overflows from nodes K3-3, K3-4, and K3 are moved to cover the region at nodes K3-1 and K3-2. In addition, the distribution of the actual flooded area is according to local resident’s reports, which may contain some estimation errors and may neglect some of records in the lightly flooded area. Thus, an inconsistency may be found in the figure, but the present analyzed model seems conservative and reasonable as it did identify more potential flooding areas during the storm period.

Figure 4. Comparison of simulated flooding areas and actual flooded record.

4. Drainage Simulation Result

The above comparison results show that the most serious flooded area is at nodes K3, K4, K3-3, and K3-4, which implies that a detention pond (Benher) may be proposed in the vicinity of this potential hazardous area to prevent flood damage. At this point, it is worthy to check the operation and control of the detention pond linked in the drainage system. Hence in the following, the design rainfall distribution for several recurrence periods and for an actual typhoon incident as indicated in the above section, are used in the model to analyze the performance of the detention pond installed in the drainage system.

Considering there exist no tidal level effect at the outfall of the drainage system, and by inputting the rainfall information for each recurrence period including 5, 20, 50, and 100 years in the drainage model. The simulated results exhibit that there are 16, 25, 31, and 33 overflow nodes for the four rainfall recurrence periods respectively, those occupy at about 19%, 30%, 37%, and 39% of the total nodes. Displayed in Figure 5 is the discharge hydrograph for the four recurrence periods at the outfall node. It can be seen that the peak drainage discharge is about 100.24, 121.61, 131.71, and 138.90 cms, for the four recurrence periods respectively.

For the water level hydrograph at lake Jinshi, the Figure 6 shows that the rain water starts to enter lake Jinshi at 59 minutes of the time for the case of 5 years recurrence period, but the
water level does not reach the critical depth (7.90m), thus it is not necessary to drain extra floodwater for this case. For the case of 20 years recurrence period, the floodwater entering time is at 53 minutes, and it reaches the critical depth at 123 minutes. At this moment, the drainage of floodwater proceeds in accordance with the operation flow chart. The system overload condition is maintained for only a few minutes, so that there is no overflow occurring downstream in this case. When the water level goes down to 6m of the expectation height at 360 minutes, the control orifice is then closed to complete the drainage procedure.

As the increasing of the recurrence period, the floodwater entering time is at 47 and 44 minutes, and the reaching time to the critical depth is at 105 and 101 minutes for the cases of 50 and 100 years recurrence period, respectively. For both cases, the system overload condition maintains 48 and 53 minutes, those result in some floodwater overflows to downstream of lake Jinshi. The curves show that the total drainage operation time last for about 266 and 271 minutes for the two cases.

For the same rainfall conditions, the water level hydrograph at the key point of detention pond Benher is shown in Figure 7 (a). It can be seen that the peak value is at 2.68, 2.94, 3.04, and 3.12m for the recurrence period 5, 20, 50, and 100 years, respectively. The arrival time is at 88, 84, 82, and 83 minutes for the four cases, but all the peak water levels do not reach the critical depth (4.32m), so it needs not to drain floodwater in the detention pond under the four design rainfalls.

By considering the tidal level effect at the outfall area, and assuming that the water level has 0.5m over the outfall drainage pipe of dimension $1.5 \times 1.5 \, \text{m}^2$ at the key point. Then, the simulated results as seen in Figure 7 (b) show that the water level at the key point is significantly higher than that of the case without tidal level effect. In addition, the peak water level due to backflow effect is at 4.32 and 4.50m for recurrence period 50 and 100 years, respectively. These peak values reach the critical depth and an operation to drain the excess floodwater becomes a requirement for these two cases. The analyzed results imply that the tidal level effect is very important as it may decrease the ability of drainage system and may cause the possibility of more flooding at the low-lying area.
5. Conclusion

In a typhoon or hurricane frequently occurred area, the drainage problem is always one of the primary concerns for the people living in this area and for the persons working in this field. At the harbor city of Kaohsiung, Taiwan, there exist some low-lying areas due to a lack of long term consideration in the city development plan. In particular, the variation of tidal level has a significant influence on the drainage system in these urban low-lying areas. Therefore, this city has to face the flood control problem during a storm period caused by a typhoon, and the installation of detention pond becomes a very important method for preventing serious flood damage in the low-lying region.

The well developed SWMM package has been used in the present study, to build up a drainage model for the Benher village including lake Jinshi in Kaohsiung city. Four different design rainfall recurrence periods including 5, 20, 50, and 100 years and an actual rainfall distribution due to typhoon Tanmei have been used as the input conditions in the drainage model. After the verification of its suitability in the simulation model, the tidal level effect at the outfall of drainage system has been investigated to check the flood drainage control process for the proposed Benher detention pond.

The analyzed results have shown that the degree of flooding is dependent on the water level at the outlet of drainage system. For all the design rainfalls, the water level at the key point was lower than the critical depth if the tidal level effect is eliminated in the simulation model. On the contrary, if the tidal level effect is considered in the model, the critical water depth was reached for the design recurrence period over 50 years. The simulated results have also shown that the detention pond could effectively to drain the floodwater under an actual typhoon storm period. Although the scale of the present study case could not compare to the flood damage in New Orleans, USA caused by the hurricane Katrina, the present developed drainage model might provide useful information for the regional harbor city Kaohsiung in Taiwan.

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Note: due to paper six pages limitation, the simulated results for an actual Tanmei typhoon with tidal level effect is not included in this short version.