論 文 の 内 容 の 要 旨

Model-based Evaluation of Hydraulic Behaviour and Pollutant Discharge Pattern of Combined Sewer Overflow Considering Characteristics of Rainfall and Drainage System

（降雨と排水区の特性を考慮した合流式下水道雨天時越流水の水理学的挙動と汚濁排出パターンのモデル評価）

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Combined sewer overflow (CSO) from urban area is recognized as a major pollutant source to receiving waters during wet weather. The concentrations of pollutants in receiving waters significantly increase after rainfall. Therefore, national and local governments in many countries have established water quality standards for receiving water body. Accordingly, CSO volume or frequency is controlled by regulations to meet the standards. Before implementing control measures on CSO, it is necessary to characterize CSO in terms of hydraulic behaviours as well as pollutant discharge and to analyze the factors affecting the variable characteristics of CSO. For example, in order to give priority to control measures, it is necessary to identify the outfalls spilling more CSO during same rainfall event or rainfall events inducing more CSO at same outfall. With regard to the pollutant from CSO, first flush is important, since it represents that higher pollutants loads are contained in the comparatively lower volume of initial discharge. For reduction of first flush pollutant discharge at outfalls, installation of storage tanks is promoted to capture more pollutant loads by intercepting lower volume of initial overflow.

It is known that CSO hydraulic behaviours represented by volume, response time, duration time are strongly affected by rainfall pattern, characteristics of catchment and sewer system. Accordingly, CSO behaviours vary significantly from one outfall to another, during the same rainfall event, or from one rainfall event to another for same outfall. However, due to the simultaneous influences from rainfall pattern represented by volume, maximum intensity, duration time and catchment or sewer system characteristics in terms of geology, topology, land use, pipe size, pipe slope, weir height and so on, it is difficult to interpret CSO occurrence and behaviours. For the same reason, the mechanism of first flush at outfalls is also not clear.

Simulation is an effective way to get CSO behaviours and pollutant loads compared to monitoring work. But, when the drainage area is large, even by simulation, it is time consuming and therefore there are few studies in which model simulation is conducted for more than one hundred of annual rainfall events. On the other hand, only with the statistical analysis on annual events, the CSO characterization is reliable and the evaluation of annual CSO volume or pollutant loads is possible. However, simulation also has disadvantages. As mentioned, it is time consuming, if considering whole annual events. Besides, since the model includes a lot of equations describing hydraulic and hydrologic process and thousands parameters related to each pipe, it is hard to identify the important parameters affecting CSO. As a result, it is not easy to take effective control on CSO through revising important sewer structure.

Therefore, the objectives of this study are 1) to characterize CSO hydraulic behaviours and identify important outfalls and rainfall events on basis of annual events simulation; 2) to assess CSO hydraulic behaviours by identifying important characteristics of catchment and drainage, and rainfall pattern without hydraulic simulation; and 3) to analyze influences of characteristics of catchment and sewer system, and rainfall pattern on pollutant discharge of CSO.

CSO behaviours in the Shingashi drainage area of Tokyo, Japan were investigated, where completely served by combined sewer system (CSS) and CSO often takes place. Total 67 outfalls are located in this area with discharging CSO. All 117 rainfall events recorded in 2007 were simulated by a distributed model of InfoWorks CS to obtain CSO hydraulic behaviours.

In chapter 4, the rainfall events were classified based on parameters of rainfall and CSO respectively. Nine and ten groups were obtained by two classifications of rainfall and CSO parameters. Clustered rainfall groups by rainfall and CSO parameters were linked by similarity analysis. Results showed that both small and extreme rainfall groups had strong correlations with the rainfall groups categorized by CSO parameters showing high similarity index of 0.75, while moderate rainfall groups had weak relationships with rainfall groups by CSO. This indicates that important and negligible rainfalls from the viewpoint of CSO could be identified by rainfall volume, maximum intensity and duration time which were applied for rainfall classification. While influences from drainage area and network on CSO behaviour should be taken into account when estimating moderate rainfall-induced CSO. Additionally, outfalls were also categorized into 6 groups by their annual behaviour indicating different levels of impact on environment.

Responding to the second objective, CSO hydraulic behaviour was assessed by rainfall pattern, the characteristics of catchment and sewer system without hydraulic simulation in chapter 5. Then the simulated and calculated CSO parameters were compared to confirm the assessment method. A threshold represented by rainfall intensity was found and if rainfall maximum intensity exceeds the threshold, CSO will occur, otherwise, CSO will not occur. This CSO occurrence threshold could be calculated by the Rational Method. In addition, three rainfall parameters were categorized for assessing CSO response time, duration time and volume respectively. They are: 1) time span from rain start to reach threshold; 2) lasting time of rainfall with more than threshold and 3) rainfall volume of more than threshold part. Results showed that for both response and duration time, more than 80% outfalls which spilled CSO at least 5 times have high R^2 (>0.8) of simulated and calculated values, and among them more than half even have R^2 of higher than 0.90. With regard to CSO volume, the calculated volumes of whole drainage during 7 different types of rainfall events were close to the simulated ones with the maximal error between simulated and calculated volume of 18%.

Finally, the total pollutant loads of SS and COD were simulated for total 61 rainfall events which induced CSO in 2007 based on hydraulic simulations. It was found that there is a linear relationship between pollutant loads and catchment size for outfalls with same threshold. The R^2 of outfalls with threshold 2, 3 and 12mm/hr are 0.98, 0.96 and 0.94, respectively. On the other hand, event-based CSO load depends on how many outfalls discharge overflow during a rainfall event. Significant high CSO pollutant load of 1,347 kg is caused by a rainfall event with long antecedent dry period. An event with large volume of 91mm also generated larger amount of pollutant load than other events causing same number of outfalls spilling.

Since pollutant load of CSO can be evaluated through the mass balance of total pollutant load from upstream catchment and load transported downstream, the relationship between these three pollutant loads was presented. Outfalls with small threshold have the highest ratio of overflowed load to the total load, ranging from 9% to

47% on basis of annual rainfall events. When the threshold reaches to 19mm/hr, the ratio of overflowed load to total load is about 0.1%.

Two rainfall parameters of antecedent dry period and maximum intensity were investigated to reveal the influences of them on CSO pollutant load. For rainfall events have similar volume, maximum intensity and duration time, the total pollutant load from upstream catchment has increasing tendency with antecedent dry period. The ratio of overflowed SS load to the total SS load has tendency of increasing with rainfall maximum intensity. Regarding to outfalls with different thresholds, the overflowed load ratio tends to decrease with the increase of threshold, though there are exceptions. The scopes of overflowed load ratio for outfalls with threshold from 2, 3, 4, 7, 8, 9, 12 and 13mm/hr are 0.91, 0.76, 0.57, 0.48, 0.66, 0.73, 0.26 and 0.13, respectively. If knowing total pollutant load which is related to antecedent dry period (ADP) and the ratio of overflowed load which is determined by rainfall maximum intensity, the CSO pollutant load can be roughly estimated.

Regarding to the pollutant discharge pattern, first flush at CSO outfalls during two heavy rainfall events were illustrated. Results showed that the occurrence of first flush depends mainly on rainfall intensity during overflow period. However, differently from common sense, first flush at CSO outfalls has no direct relationship with the initial high concentration pollutant flow from upstream or pollutant transported downstream. Instead, it more depends on whether the rainfall intensity of first stage of overflow is more than that of whole overflow period. The underlining physical meaning is that more pollutants on ground surface as well as in sewer pipe can be washed off and transported to CSO chamber by intense rainfall.