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Optimal Design of Storm Sewer Network Based on Risk Analysis by Combining Genetic Algorithm and SWMM Model

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ABSTRACT: The design of an urban storm sewer network is a costly task. Therefore, the design should be done so that the total cost becomes minimal. This requires modeling the problem in an optimization form. Floods are stochastic. Designing such a system is associated with risk. Thus, a project is optimal when both design costs and potential future risks are incorporated. This means that the selection of rainfall-runoff return period has to be based on risk analysis. SWMM software was used to handle hydraulic network simulation and the Network optimization was performed using a genetic algorithm in which the decision variables were the diameter and slope of the pipes. To calculate the cost of run-off damage, relationships for land uses, infrastructure and traffic were provided. The accuracy of the simulation-optimization model seeking the optimal design of the storm sewer network was approved by a benchmark network evaluation. The developed model was implemented in a region of Tehran city to determine the optimal design return period with a risk analysis approach. The results showed that the 10-year return period with is the optimal return period with an annual damage risk cost of 508.68 billion rials, an annual design cost of 943.78 billion rials and a total cost of 1452.45 billion rials. Therefore, the developed method in which the genetic algorithm and SWMM model are combined in addition to the risk-based design approach is an effective tool for the optimal design of storm sewer networks

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1- Introduction

Population growth, urban development, agricultural and industrial activities, and the conversion of natural lands to residential areas result in a change in the natural hydrologic cycle of the region [1]. Also, the increase of impervious areas significantly has altered the pre-urban hydrology and increased the surface run-off in urban environments compared to the undeveloped natural environments. Implementation of storm sewer networks is one of the effective ways to manage water resources. The optimal design of storm sewer networks is one of the most important issues in water engineering since they are very costly. Any attempt to reduce the construction costs of these networks can lead to significant savings. The design of storm sewer networks is always associated with risk. In a proper design, there must be a balance between its cost and the risks that may occur in the future. Therefore, both optimization and risk analysis should be considered in the optimal design. The occurrence of urban floods and the resulted damages in Iran is increasing, and consequently, the required budget to control and reduce the damages also increases. On the other hand, due to financial constraints, the dedicated budget for flood control may not be enough. Therefore, it is necessary to find the best optimal alternative with the reasonable highest efficiency in the design of storm sewer networks. Also, one of the objectives of this study is to develop proper relationships to evaluate the green area damage and the creation of traffic damage due to run-off. These relationships are used in the objective function to evaluate damage costs in the genetic algorithm optimization analysis. The decision variables are the diameters and slopes of the pipes. The optimization solver is linked to the simulation SWMM model to obtain the optimal design. The damage costs are required for the risk analysis. Relationships for the damage costs of the land use, infrastructure, and traffic, are provided for the mentioned case study. The genetic algorithm is utilized as an optimization tool to find the decision variables (pipe diameters and slopes) so that the summation of the design costs will be minimized. In this regard, the complicated method and both the rational methods (with and without) considering the flow travel time in the conduits are used and the results are compared

2- Methodology

Urban flood management is presented in this article in several main sections: 1) Preparation of simulation

model of storm sewer network including data collection and determination of desired precipitation using SWMM

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Table 1. Optimization results for different return periods

Return period	Frequency	Damage costs	Annual damage risk cost	Optimal Design cost	Annual optimal design cost
1	1	1287.89	9000	772.18	2060.07
2	0.5	989.56	10391	891.53	1881.08
5	0.2	723.64	10520	902.59	1626.24
10	0.1	508.68	11000	943.78	1452.45
20	0.05	311.84	16000	1372.77	1684.61
25	0.04	158.99	21000	1801.76	1960.75
50	0.02	0	30000	2573.94	2573.94

software. 2) Preparation of optimization model including determining goals and decision variables, selection of evolutionary optimization algorithm for storm sewer network. 3) Determining damage relationships for land uses and infrastructure and calculating run-off damage based on the relationships obtained. 4) Performance evaluation of the simulation-optimization model. The simulation model (SWMM software) is linked to the GA optimization model. The goal is to determine the storm return period with the optimal corresponding design alternative for which the total design cost plus the probable damage cost is minimum. In this regard, at the first stage, the optimal storm sewer network design for a certain selected rainfall return period is obtained. The required hydrologic data corresponding to the selected rainfall return period and hydraulic data are given to the developed model. The optimization data such as the list of the commercial pipes, the objective function, and constraints should be given to the program. Besides, the GA parameters including the initial population of chromosomes, and the mutation factor. The decision variables (pipe diameters and slopes) are initially selected by the GA. The simulation is then performed by the SWMM program. GA program calculates the objective based on the results of the simulation. The decision variables are changed by the optimization program until a minimum objective function in which all constraints are satisfied is achieved. The risk analysis is done to find the optimal storm return period. This is performed by repeating the same procedure explained above for other storm return periods. The return period is sought in which the summation of the annual costs of the corresponding optimal design and the risk damage is minimum.

3- Results and Discussion

In this section, the results of the optimal design of the storm sewer network are presented. The total annual cost introduced in column (6) shows that the 10 year is the optimal return period in which the total annual design and damage costs are minimum

4- Conclusion

In this study, a simulation–optimization program for the storm sewer network optimal design has been developed. The simulation requires hydrologic and hydraulic calculations. The hydrologic calculations involve the rainfall-runoff relationships and determination of surface run-off in the sub-catchments. The hydraulic calculations deal with flow routing in the storm sewer network. In this research, the SWMM program is linked to an optimization program that uses the genetic algorithm to develop a program that can do the simulation-optimization for the design of storm sewer networks. The performance of the developed program in terms of speed and accuracy was checked by solving a

benchmark problem. The results indicated good and successful performance. The developed program was applied for a case study design problem in a district located in Tehran city. The results showed that the optimal return period in which the total design costs and damage risk costs are minimal (1452.45 billion rials per year), the return period is 10 years.

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