Ain Shams Engineering Journal (2016) **xxx**, xxx–xxx

Ain Shams University

Ain Shams Engineering Journal

www.elsevier.com/locate/asej
www.sciencedirect.com

CIVIL ENGINEERING

Arc Based Ant Colony Optimization Algorithm for optimal design of gravitational sewer networks

R. Moeini [a,*], **M.H. Afshar** [b,1]

[a] *Department of Civil Engineering, Faculty of Engineering, University of Isfahan, 81746-73441 Isfahan, Iran*
[b] *School of Civil Engineering & Enviro-hydroinformatic Center of Excellence, Iran University of Science and Technology, P.O. 16765-163, Narmak, Tehran, Iran*

Received 20 October 2015; revised 18 February 2016; accepted 30 March 2016

KEYWORDS

Arc Based Ant Colony Optimization Algorithm;
Tree Growing Algorithms;
Optimal design;
Sewer network;
Layout;
Pipe size

Abstract In this paper, constrained and unconstrained versions of a new formulation of Ant Colony Optimization Algorithm (ACOA) named Arc Based Ant Colony Optimization Algorithm (ABACOA) are augmented with the Tree Growing Algorithm (TGA) and used for the optimal layout and pipe size design of gravitational sewer networks. The main advantages offered by the proposed ABACOA formulation are proper definition of heuristic information, a useful component of the ant-based algorithms, and proper trade-off between the two conflicting search attributes of exploration and exploitation. In both the formulations, the TGA is used to incrementally construct feasible tree-like layouts out of the base layout. In the first formulation, unconstrained version of ABACOA is used to determine the nodal cover depths of sewer pipes while in the second formulation, a constrained version of ABACOA is used to determine the nodal cover depths of sewer pipes which satisfy the pipe slopes constraint. Three different methods of cut determination are also proposed to complete the construction of a tree-like network containing all base layout pipes, here. The proposed formulations are used to solve three test examples of different scales and the results are presented and compared with other available results in the literature. Comparison of the results shows that best results are obtained using the third cutting method in both the formulations. In addition, the results indicate the ability of the proposed methods and in particular the constrained version of ABACOA equipped with TGA to solve sewer networks design optimization problem. To be specific, the constrained version of ABACOA has been able to produce results 0.1%, 1% and 2.1% cheaper than those obtained by the unconstrained version of ABACOA for the first, second and the third test examples, respectively.

* Corresponding author. Tel.: +98 31 37935628; fax: +98 31 37932089.
E-mail addresses: r.moeini@eng.ui.ac.ir (R. Moeini), mhafshar@iust.ac.ir (M.H. Afshar).
[1] Tel.: +98 21 77240097; fax: +98 21 77240398.
Peer review under responsibility of Ain Shams University.

ELSEVIER Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.asej.2016.03.003
2090-4479 © 2016 Faculty of Engineering, Ain Shams University. Production and hosting by Elsevier B.V.

1. Introduction

Sewer networks are important structure of any modern cities which are designed to protect human and environmental health. Although the design principles of sewer networks may be simple, design of least-cost sewer networks is surely not an easy task for engineers. Generally, construction of sewer networks in a city is quite an expensive task. The cost of sewer networks construction, however, can be significantly reduced if the network configuration can be effectively optimized. Finding an optimal least-cost design of sewer networks is difficult because of numerous alternative solutions and many complex hydraulic and engineering constraints. The objective function and constraints of sewer networks design optimization problem are often nonlinear and discrete leading to a highly constrained Mixed Integer Nonlinear Programming (MINLP) problem. Moreover, the size of sewer networks is generally large, therefore, leading to large scale optimization problem which is generally difficult to solve.

Various optimization methods have been proposed to solve sewer networks design optimization problem by large number of researchers. It is worth noting that computerized optimization methods have been developed in the past four decades and classified in four major categories named Linear Programming (LP), Non-linear Programming (NLP), Dynamic Programming (DP) and Evolutionary Algorithms (EA). Each of these methods has its own limitations [1,2]. To overcome the limitations of mathematical optimization methods, EAs such as Genetic Algorithm (GA), Simulated Annealing (SA), Particle Swarm Optimization (PSO) and Ant Colony Optimization Algorithm (ACOA) have been devised and used successfully to solve NP-hard problems. These methods allow a near-optimum solution to be produced within a reasonable computation time without any loss of delicate characteristics of model and any requirement of complex derivatives and deliberate initial values. In general, sewer network design optimization problem includes two sub-problems of component location (layout) and component sizing problems. Some researchers have only focused on finding the optimal size component of the sewer networks with fixed layout. In contrast, others have focused on finding the optimal layout of the sewer networks and neglected the influence of the size component on layout determination. However, these two sub-problems are not independent and should be handled simultaneously if an optimal solution is required. Haestad [3] and Guo et al. [4] reviewed the research works in the field of sewer networks design developed in the last 40 years. In the field of component sizing, LP [5,6], NLP [7–9], DP [10–16] and EA [17–29] were used by different researchers. Despite a quite large amount of researches carried out in the field of optimal sizing of sewer networks, only a few researchers focused on the more interesting problem of joint layout and size optimization of sewer network. For example, some DP [30–32] and hybrid methods [33–39] were proposed and used to solve this complex problem.

In this paper, two versions of an Arc Based ACOA (ABACOA), equipped with a Tree Growing Algorithm (TGA) are proposed and used to solve layout and size optimization of gravitational sewer network problem. The proposed ABACOA has two significant advantages namely efficient implementation of the exploration and exploitation features of ant algorithm and more importantly providing an easy and straightforward definition for heuristic information. Here, first, the combination of unconstrained version of ABACOA (UABACOA) and TGA is used to propose a formulation named UABACOA-TGA. The unique characteristics of the ABACOA along with serial features of sewer networks design problem are also used to develop a constrained version of the ABACOA named CABACOA which is the coupled with TGA leading to another formulation named CABACOA-TGA. In both formulations, the TGA is used in an incremental manner to construct feasible tree-like layouts out of the base layout while unconstrained and constrained versions of ABACOA are used to optimally determine the sewer pipe nodal cover depths of the constructed layout. Constrained version of ABACOA paves the way to explicitly satisfy the pipe slopes constraint by recognizing and excluding the infeasible regions from the search process. The proposed formulations are used to solve three test examples of different scales and the results are presented and compared with other available results in the literature. The results indicate the superiority of the CABACOA-TGA to solve large scale sewer networks design optimization problem compared to other methods.

2. Sewer networks design optimization problem

Sewer networks play a critical role in protecting public health in modern cities and improve sanitation by collecting and transporting sewage by gravity from house lateral sewer to wastewater treatment plants. These networks consist of pipe, pumping stations, force mains, manholes, and other facilities required to collect and transport wastewater. Due to high cost of sewer network construction, optimal design of sewer networks is receiving more attention.

To design sewer networks, at first, the base layout of the network should be defined. To define the base layout, existing information such as topography and sewer network area plan, the layout of other utilities, the locations of wastewater treatment plants and other existing subsystems should be collected. It is now possible to define a connected undirected graph consisting of vertices and edges and containing branched and looped subsystems. The graph vertices denote possible fixed position manholes and the location of outlets and wastewater treatment plants and the graph edges represent possible sewer network pipes located between graph vertices. Then, the areas included in the sewerage plan are determined. The service population of each area at the beginning and end of the design period, therefore, can be determined. The local sewer discharge areas are calculated using the service population of each area at the end of the design period.

The objective of any sewer network optimization problem is the minimization of the construction cost of the sewer network. The construction cost of a gravitational sewer network as a function of the diameter and the average cover depth of sewer pipes can be mathematically defined as:

$$\text{Minimize } C = \sum_{l=1}^{N} L_l K_p(d_l, \overline{E}_l) + \sum_{m=1}^{M} K_m(h_m) \quad (1)$$

where C = cost function of sewer network; N = total number of sewer pipes; M = total number of manholes; L_l = the length of pipe l (l = 1,..., N); K_p = the unit cost of sewer pipe provision and installation defined as a function of its diameter

Please cite this article in press as: Moeini R, Afshar MH, Arc Based Ant Colony Optimization Algorithm for optimal design of gravitational sewer networks, Ain Shams Eng J (2016), http://dx.doi.org/10.1016/j.asej.2016.03.003