OPTIMAL DESIGN OF SEWER NETWORK USING ANT COLONY ALGORITHM

By

Raviendra Kumar

Environmental Engg.

(2014PCE 5400)

Supervisor
Prof. Y. P. Mathur
Department of Civil Engineering

Submitted for the partial fulfillment of degree of

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In

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A

DISSERTATION REPORT

On

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June 2016

Dedication….

I would like to dedicate my thesis to my beloved parents

DEPARTMENT OF CIVIL ENGINEERING

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY

JAIPUR, RAJASTHAN-302017

CERTIFICATE

This is to certify that the thesis entitled **"OPTIMAL DESIGN OF SEWER NETWORK USING ANT COLONY ALGORITHM"** which is being submitted by **Raviendra Kumar, ID:** 2014PCE5400, for the partial fulfillment of **Master of Technology** in **Environmental Engineering** to the Malaviya National Institute of Technology, Jaipur. The work has been carried out by him under my supervision and guidance. This work is approved for submission.

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Date

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(Raviendra Kumar)

ABSTRACT

Any malfunction in sewage collection and transport may deteriorate the life of the society. Today the problem is most severe in developing country because of globalization and urbanization. The need of increase in the effectiveness and reliability of the sewage collection and disposal makes it vital to design the sewer lines and with the optimal cost of construction and operation.

Cost optimization now is becoming critical for better service. As a result, it has become an increasingly more complex task to intelligently and efficiently manage sewerage system design in ways that maximize a system's reliability and minimize its operational and management cost.

Recently, a most of the research has focused on the optimal design or upgrade of the sewerage system. It is started by a simple model linear programming, nonlinear programming, up to a slightly sophisticated Genetic Algorithm and so on, However, much of the recent, Ant Colony Optimization for the determination of low-cost sewerage system designs has been shown to have several advantages over more traditional optimization methods.

The objective of this thesis is to demonstrate that the ant colony optimization algorithm can be used successfully in the design of sewerage system based on fixed layout to minimize the overall cost of the scheme and at the same time provide a reliable and better service to users. In this thesis, a powerful and new intelligent evolution methods, called ant colony optimization (ACO) is adopted for solving the optimization problem. The proposed method was inspired by the natural behavior of the ant colonies. How they find the food source and bring them back to their nest by building the unique trail formation. The algorithm required for carrying out the steps of the ACO is not unique. In this research, a new algorithm for ACO has been proposed. The proposed algorithm is programmed in FORTRAN language and then, the Ant Colony Optimization algorithm is applied to the sewerage system design through the optimization of the objective function.

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$\alpha =$ pheromone sensitivity parameter

A = Area of Flow (m^2)

a = Cross Sectional Area (m^2)

AVG = Average of Depth of Excavation (m)

β= heuristic sensitivity parameter

CC = Concrete Cover (m)

CK = Constant K

C_{min} = Minimum Cover (m)

COSTEX = Cost of Excavation (₹)

COSTSW = Cost of Sewer (₹)

COSTMH = Cost of Manhole (₹)

$Cost_i$= cost of link I (₹)

$Cost_{max}$ = maximum cost for a particular set(₹)

D = Diameter of the Sewer (m)

DEP_EX = Depth of Excavation (m)

DEPMAX = Maximum Depth of Excavation (m)

DEPTHE = Downstream Depth (m)

DEPTHS = Upstream Depth (m)

D_{min} = Minimum Diameter (m)

d_p = Particle Size (m)

DR = Depth Ratio

ERW = Earthwork

g= acceleration due to gravity (m^2/s)

GRLE = Ending Ground Level (m)

GRLS = Starting Ground Level (m)

HMD = Hydraulic Mean Depth (m)

IANTIN = total number of ants taken for an iteration

$IANTIN_{max}$ = maximum number of ants taken for an iteration

ILDS = Downstream Invert Level (m)

ILUS = Upstream Invert Level (m)

ITN = iteration number

LINEL = Length of Sewer (m)

n = Manning Coefficient of Roughness

N= total number of pipes for a particular network

η_{ij} = Heuristic value representing the cost of choosing option j at point i

π= 3.14

P = Wetted Perimeter (m)

ρ = coefficient representing the pheromone evaporation

$p_{ij}(k, t)$ is the probability of the ant k selects option $l_{ij}(t)$ for the ith decision at iteration t;

PC = Total Penalty (₹)

PEN = Penalty (₹)

PENDEP = Penalty due to Depth (₹)

PENVMAX = Penalty due to Maximum Velocity (₹)

PENVMIN = Penalty due to Minimum Velocity(₹)

PVMAX = Maximum Velocity (m/sec)

PQ = discharge at partial flow condition

PQMIN = minimum allowable discharge at partial flow condition

PHMD = hydraulic mean radius at partial flow condition

PVEL = velocity of flow at partial flow condition

ph = pheromone intensity

Q = Discharge (m^3/sec)

r = Hydraulic Mean Radius (m)

SDD = total length of sewer

SD1 = rate of sewer at different diameter

$Slope_i$ = Slope of i^{th} link

S = Slope of Sewer (m/m)

S_f = feasible slope

S_{min} = minimum slopes that can be taken for designing

S_{max} = maximum limit for slope

SMH = Sum of No. Of Manhole

S_r = Required Slope

S_s = Specific weight of Suspended Solids

$\tau_{ij(t)}$ is the concentration of pheromone on option l_{ij} (t) at iteration t

TCOST = Total Cost of Sewer (₹)

UCSW = cost of sewer at different diameter

V = Velocity (m/sec)

V_{max} = Maximum Velocity (m/sec)

V_{min} = Minimum Velocity (m/sec)

ABBREVIATIONS

ACO = Ant Colony Optimization

DP = Dynamic Programming

GA = Genetic Algorithm

LP = Linear Programming

NLP= Non Linear Programming

PSO = Particle Swarm Optimization

SSD = Sanitary Sewer Design

SSOM = System Optimization Model

1 INTRODUCTION

1.1 The sewerage system

Sewerage network is an important infrastructure of any urban society that conveys wastewater from residential, commercial and industrial areas to sewage treatment plant. It encompasses components such as sewer pipes, manholes, pumping stations, etc.

There are three types of sewerage systems by the CPHEEO Manual on sewerage and sewage treatment'. New Delhi: published by central Ministry of Urban Dev, 1993.

- Foul sewers –A sanitary sewer or "foul sewer" is an underground concrete conduit network used to transport sewage from houses and commercial buildings to treatment or disposal. Sanitary sewers are part of an overall system called sewerage or sewage system.
- Surface water or Storm sewers – it only carries rainwater from roofs of houses and building, paved areas, pavements, and roads.
- Combined sewer – this is a single sewerage system which is used to carry both wastewater and surface water to sewage treatment plant or outlet. It is a conventional type of sewer often found in old town.

From the starting of the 20th century or so on, the reason behind the increase in concern for good water quality, higher sustainability and integrated management, the scope for sewerage system design has been expanded so widely. It covers the environment, ecology, control, management and even social aspects also. More complex hydrologic and hydraulic computer models became obtainable to be incorporated with optimization methods for a more particular design, although their safe routing methods and numerical schemes are same as those developed earlier. There is Computer tool for the design of sewerage also emerged, which greatly relieve engineers from the dull design process and enable the design to be more interactive and intuitive via graphical displays and animations.

1.2 Background

Due to rapid urbanization as well as population growth made it mandatory to enactment pollution control laws and increasing awareness towards cleanliness and sanitation, hence the problem of sewage collection and disposal mainly in the urban areas is becoming a major concern today. The significant fraction of the overall cost of waste disposal is in its initial development. Because of that to save sums of money a reliable and cost efficient design sewerage system design is needed to be developed.

The design of a sewerage system, in general, involves selection of a suitable combination of pipe sizes and slopes so as to ensure adequate capacity for peak flows and appropriate self-cleansing velocities at minimum flow. In a conventional design procedure, efforts are made to analyze several alternative systems (each meeting the physical and hydraulic requirements) and the least cost method is selected. Obviously, the outcome of such a procedure depends on a large extent on the designer experience and efforts. Notwithstanding sincere efforts on the part of a developer, it is practically almost impossible to incorporate all feasible design alternatives, and an optimal solution is not necessarily reached. Only a resources for computer oriented optimal designing may be a solution.

Researchers have heavily interested the topic optimal sewer design. Its concept was first proposed by Deininger, 1966 and Holland, 1966. When advances in the computer power shone a light on engineering research. Since the 1970s and 1980s simulation models and optimization technologies became computationally tractable and flourished. Various optimization techniques were developed earlier, including Linear Programming (LP) Deininger, 1966 and Dajani, 1974. Nonlinear Programming (NLP) by Holland, 1966 and Dynamic Programming (DP) by Mays, 1975; Walters, 1979.

Recently, Dorigo et al. Proposed a new evolutionary optimization method, the ant colony algorithm is based on the collective behavior of the ants. How ants search for food from their source to the destination where they have to carry the food. There are so many applications of this algorithm since it has developed. One of that is in the solution of difficult combinatorial optimization problems, e.g. the quadratic assignment problem (QAP) and the traveling salesperson problem (TSP).

1.3 Present work

The sewage water collection system considered in the present investigation incorporates all about the gravity collection main. The optimization of such a system or extension thereof necessarily constitutes minimization of a nonlinear cost function subject to various linear and nonlinear constraints.

In such a problem, techniques of linear programming (Elimam, et al., 1989), non-linear programming (Khanna, 1974), dynamic programming (Gupta, et al. 1983) or evolutionary/meta-heuristic techniques (genetic algorithms, simulated annealing, and ant colony optimization) are suitable.

In this thesis, the problem with a branched gravity sewer system design is to be treated as a multi-option system serial multi-stage, composed of a series of manholes and sewer pipes. An optimal hydraulic design is made possible by selecting an appropriate diameter and slope for each pipe, and sewer from the set of available different commercial pipe sizes available in the market, which is evaluated by a detailed hydraulic analysis, the goal of which is to meet the design criteria at a minimal cost. In the modeling one also has to supply a set of design variables (for to the various construction modes) for sewer system design problems. This approach can lead to obtaining design results that compared with other optimization models and techniques are more practical and cost-effective Ultimately, a case study of a 100-manhole project is carried out to evaluate the minimum cost for a particular network layout

1.4 Objective of the study

- The primary purpose of this study is to understand and describe the different type of sewer network in the society and to compare their design and performance based on the cost of construction and maintenance and to know about the relation between the hydraulic and design parameter of a sewerage system.

- So many models and techniques are developed in the past in the optimization of the sewer network. I also want to contribute my knowledge of sewer design to make the better future of the sewerage system in the society
- The key objective of the thesis is to show how an ant colony optimization algorithm can be used successfully in the design of sewerage system to minimize the overall cost of the scheme. In my thesis work, a new and powerful evolution method, called ant colony optimization (ACO) is implemented to solve the optimization problem. It is a population-based method that uses the investigation of positive feedback as well as greedy search. The proposed method was inspired by the natural behavior of the ants how they find their source of food and return to their nest by leaving the unique trail formation.
- Usually, the algorithm required for carrying out the steps of the Ant Colony Optimization is not unique. But in this research, a new algorithm for ACO has been proposed. The proposed algorithm is coded in FORTRAN program software. The performance of a hypothetical case has been evaluated using FORTRAN to test the effectiveness and validity of the proposed algorithm. Also, the studied sewerage system network has been analyzed using the program developed for sewerage system network analysis to check the results obtained from the FORTRAN program for the prescribed constraints, in addition to performing other evaluations. The results obtained show that the suggested way of the method is promising in the optimal design of the sewerage system.

1.5 Organization of the report:

This report has been prepared to provide a detailed description of the use of the ant colony optimization approach to sewer systems and the program developed can also be applied further to optimize any sewerage system network.

In Chapter 2, a brief overview of optimization of a sewer system and a basic introduction to different optimization techniques that can be used for sewer system design are presented.

In Chapter 3, a brief description about the sewer system, its components and types are shown. Besides these, various factors that need to be kept in mind while designing a sewer system are also discussed briefly and the hydraulic principles to be considered in a flow through the sewer system network are also mentioned.

In Chapter 4, a detailed description of Ant colony optimization techniques for better understanding along with a generalized flowchart is presented and its various applications apart from the sewer system.

In Chapter 5, the optimization problem is formulated a single objective optimization problem with equality and inequality constraints to be followed. The problem of optimizing a sewer system is converted into a target function. The constraints applied to the model are decided. The penalty function is defined that whenever any of these constraints will be violated a penalty will be added, finally reaching to the overall expression that will be further minimized.

In Chapter 6, a computer-based program to solve the optimization problem using the proposed method and the methodology of Ant colony optimization algorithm for the network has been discussed. Starting with a basic knowledge introduction to the FORTRAN language, its characteristics, and then the procedure for optimizing sewer system design is gives step by step with the help of two flowcharts (1 flowchart for sewerage system analysis and 1 for ACO).

In Chapter 7, the results of the optimization method are presented along with the tables for input data. Also, the comparison of starting solution and the final settlement is also done to see the effect of ACO on sewerage system design

Finally, the conclusions are presented in Chapter 8.

2 LITERATURE REVIEW

2.1 Sewerage system

Sewerage system offers significant advantages and exciting possibilities for sustainable development of the idea of sustainability. A rural sewerage system can not only be an essential facility for draining waste water to protect the rural environment and public water bodies. But it also contributes to the restoration of the water environment for maintaining the healthy social water cycle. A human water cycle is defined as a system that includes drawing water from natural bodies, utilizing it and discharging back to the water bodies *(Zhang, 2007)*

2.2 Sewer System design

Swamee (2001) was the researcher to highlight the need for sewer hydraulic design, he highlighted the research history by the previous researchers on the sewer network design.

Merritt and Bogan (1973), Argaman et al. (1973) contributed their knowledge to the design of sewer network by using the approach dynamic programming.

Linear programming problem also solved the by Dajani et al. (1972), Dajani and Hasit (1974), and Elimam et al. (1989) using piecewise linearization. Jain (1987) and Tyagi (1989) developed a sequential linear programming method to find the diameters of the sewers. Gupta et al. (1976) used Powell's method for conjugate directions to search the optimal of the cost function.

Swamee (2001) described in his paper that construction of a sewer network includes the major portion of the cost of the sewage system. In the sewerage system design, the sewer line is the basic unit occurring repetitively in the process of design and any reduction in the cost during the design of a particular unit will upset the overall cost of the sewer system.

The main constraints in the optimal sewer design are presented below, some or all of which may be adopted in sewer design practice:

- A minimum velocity constraint avoids build-up of sediments.
- A minimum pipe slope to prevent adverse slopes results by inaccurate construction or settlement.
- A minimum cover depth constraint level protects buried pipes from surface damage due to external load on the surface over the sewer line
- A minimum pipe size commercially available is adopted based on experience.
- The crown level of a pipe leaving a manhole should not be higher than those entering the pipes.
- The conduit, leaving a manhole has a diameter greater than or equal to any pipe opening to avoid physical blockage.
- No extra or pressurized flow occurs, in that way preventing pollution through leaky joints.

2.3 Optimization of sewerage system design

In conventional sewer design, the basic principle was that all drain conduits should be intended to deliver a free-surface flow so that an unpressurized condition could be ensured. The relationship between pipe size and its capacity is almost based on the hydraulic resistance equations, the Manning equation, and Colebrook-White equation. For a given design flow (velocity or discharge) and pipe roughness, these equations can be used to determine the size of a sewer. To do the simple calculations, a steady flow approximation is desirable. In designing a network layout, each pipe is assumed as an individual entity and in a sequence from upstream to downstream. The design of sewer network is only based on the concept of keeping pipe slopes as flat as possible, giving a feasible but over-expensive solution unless the optimization is introduced.

The optimization of sewer design aims to reduce the network initial construction cost and to ensure an excellent system performance also. Depending on the problem formulation, the sewer design problem can be considered as a single-objective or multiple-objective optimization problem constraints by some factors. Its general form can be defined as follows:

$f(p) = \min [f_1(p), f_2(p),,,, fn(p)]^T$

Subject to $g_i(p) = 0$ for $i = 1, 2, \ldots, k$

$h_j (p) = 0$ for $j =1,2,\ldots, l$

Where: $x = [p_{1,} p_2 \ldots p_m]^T$ decision variable vector, T problem dimension

$g(p)$ sets of inequality constraints and

$h(p)$ sets of equality constraints

During the design, the optimization technique is integrated with a sewer network hydraulic simulator; that evaluates the hydraulic performance of each potential solution. As Compared to the old-fashioned design method, the optimal sewer design validates several distinct advantages:

a) It solidifies a potentially valued and practical solution for rigorously incorporating local economic considerations into the hydraulic design process (Dajani, 1974).

b) It aims to obtain the economical design solution while providing more trustworthy serviceability. In this way, it can avoid the oversized pipes that may lead to a lower flow velocity and increment in the sediment deposition and so blockage in the pipes (DoE/NWC, 1981).

c) It allows sewer engineers to examine a great number of scenarios and deliver more design alternatives, implementing potential swaps among several design objectives.

d) It considerably eases the whole design process by automatic computer-based design and discharges designers from tedious manual calculations related to the design.

e) It can work strictly with cultured simulation models, providing the possibility of detailed analysis of the dynamic drainage method, and leading to optimization solutions that are hydraulically more correct and consistent.

Various researchers are using the technique of nonlinear programming, linear programming, dynamic programming, particle swarm analysis (PSO), genetic algorithm (GA), and Ant Colony Optimization (ACO) algorithm.

2.3.1 Dynamic programming

The cost of sewerage systems constitutes a major fraction of the overall cost of wastewater disposal. This procedure is not practical at present due to limitations in computer space and computation time. An alternative, more restrictive, the process has been proposed by which a suboptimal design can be obtained with a reasonable computational effort. This optimization process has been applied to small sewerage networks, both hypothetical and real, where its usefulness was clearly demonstrated. Large sewerage systems may be decomposed into small subsystems, which are optimized internally, and later recombined to a single optimal network (Yerachmiel Argaman, 1973).

Dynamic programming is a technique well suited for the optimization of a multistage decision problem where the decision is to be made sequentially at different points and different levels. Prepared a computer program incorporating dynamic programming technique in the sewer system design (LaVere B. Merritt, 1973).

Design Optimal and simulation of storm and sanitary sewer networks has mostly been treated by dynamic programming (DP) and heuristic methods. DP methods are the most used method for optimal design of storm sewer networks due to the serial features of these networks. (Robinson, 1981), (Kulkarni, 1985), and (Li G, 1990) employed DP to design wastewater and/or stormwater network optimization. Curse of dimensionality is the root problem with the DP methods which are theoretically capable of finding the global optimum solution.

The approach consists of two DP models: a collection system with a fixed benefit assessment technique to recognize areas for wastewater collection; and a model of the transportation system to select ways of wastewater conveyance. Unlike unoriginal benefit analysis, advantages of this method are defined as changes in contrary, environmental, public health, and other noneconomic concerns as a result of sewerage necessities. The approach is a useful decision instrument for a planning sewerage system extension. The models are used to recognize "best" sewerage expansion plans for Ensenada, Baja California, Mexico. Sixteen potential areas for sewerage development and three existing plants with additional wastewater treatment capacity are considered (M. Rashid, 2011).

2.3.2 Linear programming

There have been some efforts using the linear programming (LP) method to crack the problem of storm water designs. (Elimam, 1989) developed a approach combination of LP and a heuristic approach to design large-scale storm water networks. Heuristic approaches have been used recently for the problem due to their simplicity with good results having been reported using these methods. (Miles, 1988)used a heuristic method and (Heaney, 1999) employed a GA on spreadsheet templates to get near optimal solutions for these problems.

Linear Programming is a unique form of mathematical technique. It can easily handle a large number of decision variables and implement the optimization in an efficient, reliable and deterministic manner (Yufeng, 2008). The methodology poses several strict requirements for its implementation:

i. All objective functions and constraints should be linear. However, it is very difficult to have a linear relationship with decision variables, such as pipe diameters and slopes;

ii. The implementation of the LP requires individual segments of the problem to operate independently as well together. This certainly requires each pipe to be designed individually, and indicates that each pipe flow does not depend on flows in adjacent pipes, which, even for a tree like a network, is only true in a steady state condition (Yufeng, 2008).

iii. All the decision variables are taken as continuous variables. Its solutions often include continuous diameters, which have to be accustomed by rounding each continuous diameter up to its nearest commercial size.

2.3.3 Nonlinear programming

A methodology to design a sewer system using a nonlinear programming approach is developed. It is a five-step approach. The cost function in nonlinear programming method consists of the purchase and installation cost and the excavation costs of all pipes.

It is a convex problem of programming; that’s why the minimum solution is an absolute minimum (Lemieux, 1976).

Nonlinear Programming techniques can generally deal with nonlinear objective functions and constraints, but entail much increased computational difficulty due to the discontinuous and non-differentiable objective function. Moreover, most of them could not deal with discrete diameters (Gidley, 1986). There are so many difficulties encountered during the application of mathematical programming techniques. LP and NLP, had limited success and soon fell out of favor with researchers when more advanced optimization techniques emerged.

For the above-described reasons, Linear, NonLinear and Dynamic Programming appear insignificant to delivering comprehensive and sophisticated sewer design. earlier practice using these techniques, the sewer design problem was mostly handled as a pipe sizing and a slope design problem with a fixed plan layout. Comparatively little research has been involved with designing the sewer network layout, that is to say location number and of manholes because it significantly increases the complexity of the optimization task (Walters, 1995).

In the late1980s, some design tools also came into view, varying from the spreadsheet model (Miles and Heaney, 1988; Brown and Koussis, 1987) to more user-compatible and easy to implement computer programs (Yen, *et al.* 1984; Chau, 1992). Though computer models produced more accurate and favored solutions, restrained by technologies of the time in related disciplines, design practices generally entailed many modeling simplifications and limitations. Typically, maintaining system continuousness and satisfying different design constraints poses practical difficulties in design. The solutions cannot be guaranteed to be the right optimum because some methods find out fewer options and will terminate the optimization once a feasible solution is found (Heaney, *et al.* 2002).

2.3.4 Genetic algorithm

since the last decade or so on, due to increased consideration of water quality, sustainability and integrated management, the sewer system design scope has been greatly expanded to involve a wider spectrum, Since Cembrowiczand Krauter (1987) made an effort to use Evolutionary Computation (EC) for sewer optimization, Evolutionary Computation methods, particularly genetic algorithms (GAs),have been the most popular and optimization techniques for this task (Cembrowiczand Krauter, 1987; Walters and Lohbeck, 1993; Heaney, *et al.* 1999; Afshar, *et al.* 2005).

Genetic Algorithms encompass many advantages as Compared to the conventional type of optimization methods:

1. They are independent of design objectives, and therefore it is not necessary to deploy objective functions. Genetic Algorithms can deal with any of the systems without the need for special simplifications on system representation. In such way, an accurate and complete evaluation of hydraulic system performance becomes possible.
2. Since the sewer network is simulated and evaluated as a whole, flow continuity can be automatically sustained. The essential storage capacity of the system, provided by pipes and manholes, can be utilized for a design seeing flooding (Butler and Davies, 2000).
3. Common effects exist between sewers, a small change in a remote part of the sewer network may have considerable effects downstream. In reverse, downstream hydraulic situations may be propagated backward, especially when flooding or surcharging conditions occurs. Hence, the design should consider the system performance globally.
4. GAs generally works in a quasi-exhaustive search manner. So that in this method the more chance is that correct optimal or near-optimal solutions may be found.

GAs can easily deal with optimization problems having multiple objectives, which are generally intractable for older methods. Multi-objective optimization is required for sewer design due to the nature of design criteria, typically hydraulic performance and capital cost

The Adaptive GA is another tool to design a sewer network. This is designed so that each chromosome having a diameter and slope is a feasible solution. And there is no need to put a penalty function to main objective function (Haghighi and Bakhshipour, 2012).

2.3.5 Particle swarm analysis (PSO)

Particle swarm optimization (PSO) is a population based technique and a stochastic optimization procedure developed by Dr. Eberhart and Dr. Kennedy in 1995. They design it, inspired by social behavior of bird flocking or fish schooling (Kennedy and Eberhart, 1995).

PSO stakes many parallels with evolutionary computation techniques such as Genetic Algorithms (GA). The system is initialized with a population of random solutions and searches for optima by updating generations. In PSO, the potential solutions, which is called particles, fly throughout the whole problem space by following the current optimum particles (Lovbjerg and Krink, 2002).

Each particle retains path of its coordinates in the space of problem which are connected with the most suitable solution (fitness). This value is called *best*. Another "best" value which is finding out by the PSO is the best value, achieved so far by any neighboring particle in the neighborhood. This location is called *lbest*. When a particle takes all the population as its topological neighbors, the best value is a global best and is called *gbest* (Chen and Zhang, 2010).

The PSO concept consists at each time step, Chang in the velocity of (accelerating) its each particle in the direction of its *lbest and* p*best* locations (local version of PSO). And then acceleration is weighted by a random number, with separate random numbers being generated for acceleration toward *pbest* and *lbest* locations (Roy, 2012).

In past years, PSO has been applied successfully in many research and application areas. It is verified that PSO provides better outcomes with high convergence.

A new modification in the sewer design with PSO is that we can generate a different layout for the same area network. And this is done by choosing the best combination of minimum discharge and minimum length of travel (Navin and Mathur 2016).

2.3.6 The ant colony optimization

The ACO is a optimization technique which is based on probability model for solving computational problems through graphs.

At first, the ACO was proposed by Marco Dorigo in 1992 in his Ph.D. thesis. This algorithm belongs to the ant colony algorithms family, in swarm intelligence methods, and it constitutes some metaheuristic optimizations. The first algorithm was to examine for an optimal path in through graph, based on the behavior of ants looking for a path between their colony and a source of food. The original idea has since ramified to solve a wider class of numerical problems, and thus, many problems have emerged, drawing on various aspects of the behavior of ants.

Ant colony optimization algorithms are designed for discrete optimization problems in which the value of the decision variable is to be selected from a discrete set of possible values. Application of these algorithms to continuous optimization problems requires the transformation of the continuous search space to a separate space by discretization of the continuous decision variables. In this procedure, the continuous allowable range of decision variables is discretized into a distinct set of acceptable values, and a search is then conducted over the resulting discrete search space for the optimum solution (Abbaspour, 2001; Vitkovsky, 2000).

ACO associated with the tree growth algorithm is utilized in finding an optimal solution for a sewer network.TGA is used to generate a tree like growing structure of the basic feasible solution (Ramtin and Afshar 2013).

Over the time, however, the pheromone trail starts to evaporate, and so its attractive strength gets reduced. If the more time an ant will take to travel down the path and back again, the more will be the pheromone evaporation. That means A short path, have more strength of pheromone by comparison. So it gets followed by ant more frequently, and thus, the pheromone density will remain higher on shorter paths than longer ones. Subsequently, when one of the ants finds a good (i.e., short) path from the number of options available, all other ants prefer to follow that path, and positive feedback ultimately leads all the ants following a single path. And this approach is applied in the field of sewer design this behavior is simulated by using artificial ants.

Swarm intelligence is a relatively a modern approach to problem solving that takes inspiration from the insects and other animal’s social behaviors. Ants have been inspired by so many methods and techniques. It is a general purpose optimization technique known as ant colony optimization (Dorigo et.al 2006).

In this paper describes the Continuous Ant Colony Optimization Algorithm (CACOA) newly introduced to optimize the design of the sewer network fix layout. To implement the algorithm two alternative methods are presented and nodal elevation of the concerned network is calculated (Afsar 2010).

3 SEWERAGE SYSTEM

The sewerage system is the network or system of sewer and associated works designed for the collection of foul sewage or wastewater, conveying it via pipes, discharging it at a treatment work or other place of disposal. It comprises various subsystems, and each subsystem is required to be designed in detail, keeping in view the objective, data and background information available.

The main objective of the sewerage system is to carry sewage or effluent from domestic or industrial or any other source point to the treatment plant in accordance with all current relevant legislation. A sewer main is provided to meet the consumer requirements.

Due to rapidly increasing the need for better sanitation and population growth facilities, enactment laws of pollution control and increasing awareness towards sanitation, the problem of waste water collection and disposal i.e. becoming a major concern today. The initial development cost of a sewage collection facility constitutes a major fraction of the overall cost of waste disposal. Therefore, substantial sums of money can be saved by improving the sewerage system design.

Sewerage system offers important advantages and interesting possibilities for sustainable development of the idea of sustainability. A sewerage system can not only be a basic facility for draining waste water, but also contributes to the restoration of the water environment for maintaining the healthy social water cycle (Zhang, 2007).

A gravity sewage system could be a multi-stage multi-option system composed of pipes and manholes. For each pipe stage, there is a unit many totally different business pipe size obtainable as choices.

3.1 Types of sewerage system

3.1.1 Based on Carrying Water

Sanitary Sewerage System

This system is designed to receive domestic sewage and industrial waste excluding stormwater. This system is composed of various sewer lines terminating at the junction of a large sewer line. The large sewer line also ends at the junction of a still more major sewer line. Finally, the main sewer line ends at the outfall. This system carries the sediments to the treatment plants, where it can be removed.

Storm Sewerage System

The storm sewerage system carries rainwater from paved roof areas, pavements, and roads. Storm water, sewers are usually much larger than sanitary sewer systems because they are designed to take much more significant amounts of water. (Mara and Alabaster, 2008).

Combined Sewerage System

This system takes domestic water, industrial water, and storm water. During wet weather, the combined volume of wastewater and stormwater runoff entering in sewerage system often exceeds conveyance capacity.

3.1.2 Based on technology used

Conventional Sewerage System

The traditional sewer system is an offset technology to carry the wastewater from the house to the treatment plant. These are typically employed in urban areas with consistently sloping ground, and these are employed in the city. These are not excellent for the hills or flat areas as it results in deep excavations. These are also not good for the areas where the water level is high (Gardner, 2004). The minimum cover of 1m should be provided. In this system, manholes are provided at the upper end of all laterals, change in direction, slope, and junctions (CPHEEO, 1993). This system can handle grit and solids in sanitary sewage.

Simplified Sewerage System

Simplified sewerage is an off-site sanitation technology that removes all wastewater from the household environment (Bakalian et al., 1994). This system was developed for low-income areas. Where there is an insufficient space problem for the on-site system (Sarmento, 2001). It is applicable in all situations, but especially suitable for areas characterized by gently sloping topography, a high and low-dense population with reasonably water supply, small homesteads with the high water table lack of space, impervious soil and shallow bedrock. These sewer systems are cost effective at lower densities than the other (D, 1996; Mara, 2008). In India, there is only one place (Ramagundam in Karimnagar district of Andhra Pradesh) where this system is being tried (Nema) (D, 1996; Mara, 1996).

Small Bore Sewerage System

These systems are designed to receive only the liquid portion of the household wastewater for off-site. A septic tank is associted in this type of system to prevent the entry of slit, oils and other troublesome organic and inorganic solids which might cause an obstruction in the sewer. Lesser the possibility of clogging lesser the diameter that can be used. They can also be effective where the topography is too flat without deep excavation, where the soil is rocky or unstable and where the ground water level is high, domestic water consumption is small, water-saving plumbing fixtures and appliances are widely used (Metcalf and Eddy, 2002; D, 1996).

3.2 Design considerations

3.2.1 Introduction

Many design & construction factors need to be considered before sewer design can be completed. Such factors as design period, peak, average and minimum flows; drain slopes and minimum and maximum velocities; design equations; sewer material; joints and connections, appurtenances, and sewer installation;, etc., are all important in developing sewer design. ‘Manual on sewerage and sewage treatment,’1993 contains recommendations and guidelines on these factors based on practical considerations. Some of the primary elements, used in the present work, are briefly discussed below.

3.2.2 Design Period

The length of time up to which capacity of sewer will be adequate is referred to as design period. A design period of 30 years (excluding the construction period) is recommended for all types of sewer (CPHEEO manual 1993).

3.2.3 Flow Assumptions

The discharge quantity in sewers varies considerably from hour to hour and also seasonally, but for the purpose of hydraulic design, it is the estimated peak flow that is adopted since it is both challenging and uneconomical to augment the capacity of the sewer system at a later date. The peak factor depends on upon the contributory population.

Table 3-1: Recommended Values of Peak Factors

Population	Peak Factor
Less than 20,000	3.00
20,000 to 50,000	2.50
50,000 to 7,50,000	2.25
Above 7,50,000	2.00

Source: CPHEEO ‘Manual on Sewerage and treatment’, 1993

3.2.4 Per Capital Sewage Flow

Although the entire spent water of a community should contribute to the total flow in a sanitary sewer, a small portion may be lost to evaporation, seepage in ground, leakage, etc. In some arid areas the fraction reaching the sewers may be an as low as 40% while for an intensely developed area, it may be high as 90%. 80% of the water supply may be expected to reach the sewers unless there is data available to the contrary (Manual on Sewerage and sewage treatment’, 1993)**.**

3.2.5 Self-Cleansing Velocity

The self-cleansing velocity is the minimum velocity of flow, which is necessary to avoid the deposition of the solid particle at the bottom. Self-cleansing velocity (V) is determined by examining the particle size (d_P) and the specific weight (S_S) of suspended solids in sewage. This may be calculated by an empirical Shields’ formula:-

$$V= 3 \text{ to } 4.5 \{g. (S_S-1) d_P\} ½$$

Usually a minimum velocity of 0.8 meters per second (M/S) at peak design flow is recommended in the sanitary sewers with a minimum of 0.6 mps for present peak flow. Lesser velocities encourage stable deposition and production of hydrogen sulfide and methane. Hydrogen sulfide gas causes odors and corrosion, and methane may even cause explosions.

3.2.6 Erosion and Maximum Velocity

As the sewage contains very fine solid particles. It may act like abrasives if the velocity of flow is high. Erosion on the sewers surface is caused by sand and other abrasive gritty material in the sewer. Thus, the maximum velocity needs to be kept within limits depending upon the martial of the sewer as given in Table 3.2

Usually, velocities higher than 3.0 m/s should be avoided as erosion and damage may occur in the sewer or manholes.

3.2.7 Minimum allowable diameter of sewer

For a public sewer where the flat slopes are favorable minimum diameter is kept not below 150 mm. However, for hilly areas where extreme slopes are prevalent, minimum size may be 100 mm.

3.2.8 Cover depth

The depth of the sewers below ground surface is kept usual to provide a minimum soil cover of 1.0 m. This minimum cover is provided from traffic considerations and other consideration of avoiding frequent exposure of laid sewer for example, due to the construction of open drains, providing house connection of telephone, electricity, water, etc. The maximum depth (usually not more than 6-7 m) depends on the water table, lowest point to be served (ground floor or basement), topography freeze depth and the practical viability.

Table 3-2 Non-Eroding Limiting Velocities In Sewers

Sewer Materials	**Limiting Velocity in m/sec**
Vitrified tiles & glazed bricks	4.5-5.5
Cast iron sewers	3.5-4.5
Stone Ware sewers	3.0-4.0
Cement Concrete Sewers	2.5-3.0
Ordinary brick lined sewers	1.5-2.5
Earthen Channels	0.6-1.2

Source: CPHEEO manual 1993

3.2.9 Appurtenances

Sewer appurtenances include Manhole, building connections, junctions chambers or boxes, terminal clean outs and others. Manholes are generally provided at every junction, change in sewer direction / size, drop, etc. Manholes for small sewers are typically 1.2 m in diameter. For larger sewers (exceeding 600 mm), larger bases with barrels of same 1.2 m size may be provided. The spacing between the manholes depends on upon typography and sewer cleaning device in use. The straight runs between manholes are limited in length to 30m for sewer upto 300mm size where manual Roding is adopted. From Above 300 mm DIA sewers with mechanized cleaning, they may go up to 90m to 150-meter cleaning. The Manholes should also be provided at every junction, change of alignment, size and gradient.

Area:

The area should be calculated by the following formula:

$$\text{Area} = 0.25\pi D^2$$

Bed Slope 1 in:

Maintain a uniform slope that provides an allowable minimum and maximum velocity. A flatter slope that is sufficient enough to maintain a velocity of 0.6 m/Sec will be permitted only in special cases. Where it is necessary to exceed 3 m/Sec, consider using drop structures (Bureau Of Local Roa Streets, 38-2 (2), Drainage Design, 2006).

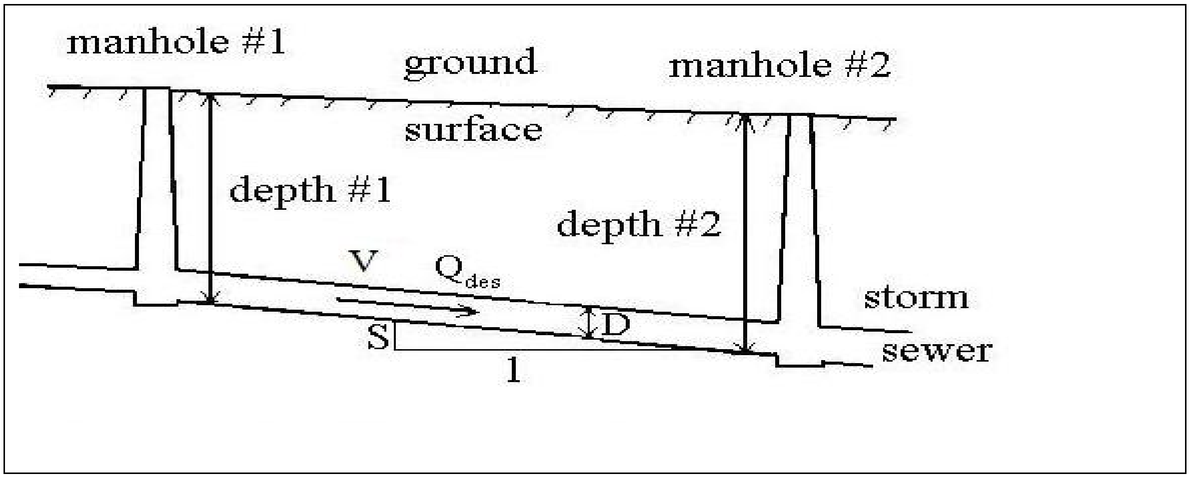

Figure 3-1 Side view of sewer pipe

Hydraulic Mean Depth (HMD):

Hydraulic mean depth should be calculated by the following formula:

$$\text{HMD} = \text{Area} / \text{Perimeter}$$

Velocity:

The Hazen–Williams formula is frequently used for the design of large-diameter pipes, without regard to its limited range of applicability. Available information shows that the appliance of the formula is correct provided that the operation of the pipe is found at intervals the transition or sleek flow regimes (García, 2003).

The Manning equation, however, has received the most widespread application. The equation is given below:-

$$V = 1/n\ r^{2/3}\ s^{1/2}$$

Where, V = velocity in mps, S = Slope of sewer (m/m), r = hydraulic mean radius (m) = wetted area/wetted perimeter, n = Manning coefficient of roughness

Discharge (QA):

Discharge should be calculated by the following formula:

Q = AV

Where = discharge (m^3/sec), A = Area of flow (m^2), V = velocity of flow (m/sec)

Fall:

The fall during a pipe is outlined because the vertical quantity by that the pipe drops over a distance. Space is often between sections of pipe or between manholes. Fall in channel link calculated by the subsequent.

Fall in channel link = Length / Bed slope one in

Invert Levels:

The bottom of the pipe wall is called the invert. The upstream invert level and downstream invert level should be calculated by the following formula:

ILUS = GRLS - Cover - D - 0.02

ILDS = ILUS - Fall in channel

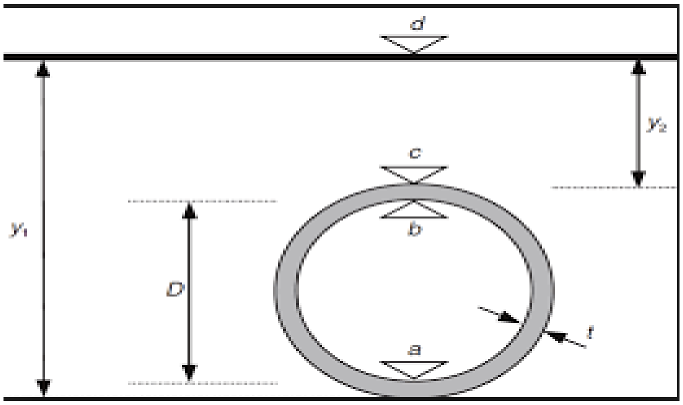

Figure 3-2: Invert level

Earthwork:

Earthwork should be calculated by the following formula:

ERW = Length X Width

Depth of Excavation:

DEP_EX = ((DEPTHS+DEPTHE)/2) + CC

Where

DEPTHS = GRLS - ILUS

DEPTHE = GRLE - ILDS

Part full flow

Various expressions are also available for flow under partial flow conditions. From the Manning formula and continuity equation, we get"-

$$q = a\,v$$

$$= a\ 1/n\ (a/p)^{2/3}\ (s)^{1/2}$$

Where q = discharge (Cumec), a = area of flow (sq.m), p = wetted perimeter (m)

Constant *K*:K should be less than 0.318.

$$CK = QnD^{-8/3}S^{-1/2}$$

Cross *Sectional Area*

The cross-sectional area of flow can be computed for a known value of angle of flow ‘θ’ using the relationship:

$$A = D^2 \frac{\theta - \sin\theta}{8}$$

Depth *Ratio:* Depth ratio can be calculated by

$$\frac{h}{D} = \frac{1}{2}\left[1 - \cos\left(\frac{\theta}{2}\right)\right]$$

Hydraulic *Mean Depth:* Hydraulic mean depth can be calculated by

$$HMD = 0.25D\,(\theta - \sin\theta)/\theta$$

Depth *of Flow:*

Depth=DR X D

Theta

Saatci A. (1990) gave an expression for computing values of ‘θ’ directly for given values of D, Q and S:

$$\theta = \frac{3\pi}{2}\sqrt{1 - \sqrt{1 - \sqrt{0.0217\pi}}}$$

This is an expression based on regression analysis is valid for θ within the range of 0 to 265 degrees.

The parameters on the right-hand side of the equations are known. Thus velocity can be computed directly, although certain small errors may be associated when compared with values computed using standard analytical formulae.

Table 3-3: Manning's Coefficients For Various Materials

Conduit Material	Manning's Coefficients
Salt glazed Stone Ware	
a) Good interior surface	0.012
b) Fair interior surface	0.015
Cement Concrete Pipes with Collars	
a) Good interior surface	0.013
b) Fair interior surface	0.015
Cast Iron	
a) Unlined	0.013
b) With spun cement mortar lining	0.011
Spun Concrete Pipes (PSC & RCC) with socket spigot joints	0.011
Steel	
a) Welded	0.013
b) Riveted	0.017
c) Slightly tuberculated	0.020
d) With spun cement mortar lining	0.011
Asbestos cement	0.011
Plastic (Smooth)	0.011

Source: CPHEEO manual 1993

4 ANT COLONY OPTIMIZATION

4.1 Introduction

As the name indicates an ant colony optimization is an approach derived from the inspiration. This method is based on the fact that how ants decide the best way to travel between their colony to a food source. The ACO was first introduced by scientist Dorigo in 1992 during his Ph.D. work.

An important and exciting behavior of ant colonies is their foraging behavior, and, in particular, the way of ants to find shortest paths from food sources to their colony. During movement from food sources to the nest and vice versa, ants leave a special substance called pheromone,on the ground. All the ants have ability to smell pheromone and, when choosing their way; they tend to choose, in probability, paths marked by pheromone concentrations. A ant feel and analise the pheromone and select the root where it is more comparatively (Dorigo, 1966).

Ant colony optimization is a population-based metaheuristic method proposed (Dorigo, 1992). By imitating the foraging behavior of ant colonies, ACO aims to search for solutions to the combinatorial problems, where a colony of artificial ants combines prior information about the promising solutions with posterior information about the best found solutions (Dorigo, 1996).

This particular behavior of ant colonies has inspired The Ant Colony Optimization (ACO) algorithm. In this approach a set of artificial ants behave like real ants to find solutions to a given optimization problem depositing pheromone trails throughout the search space (Dorigo, 1966). ACO has proven to be an efficient and versatile tool for solving various combinatorial optimization problems.

The tendency to choose a path is described by a probability that increases with the number of ants having chosen the same route in the preceding iterations. An ant encountering a previously traversed path and the pheromone-laid trail can decide with high probability to follow it and subsequently reinforce the trail with its pheromone. As a result, the path traversing quickly converges to the shortest path. In summary, ACO constructs the solutions in a probabilistic way by taking into account pheromone trails which change with each iteration and a heuristic information depending on the problem to solve (Zhang, 2012).

In Figure 4.1, ants walk between two points via the unobstructed path. When an obstacle breaks the path ants try to get around the obstacle randomly choosing either way.after some trials remaining all ants feels pheromone on both the way and select the shorter path. This feedback leads soon to the final stage, where an entire ant colony uses the shortest path.

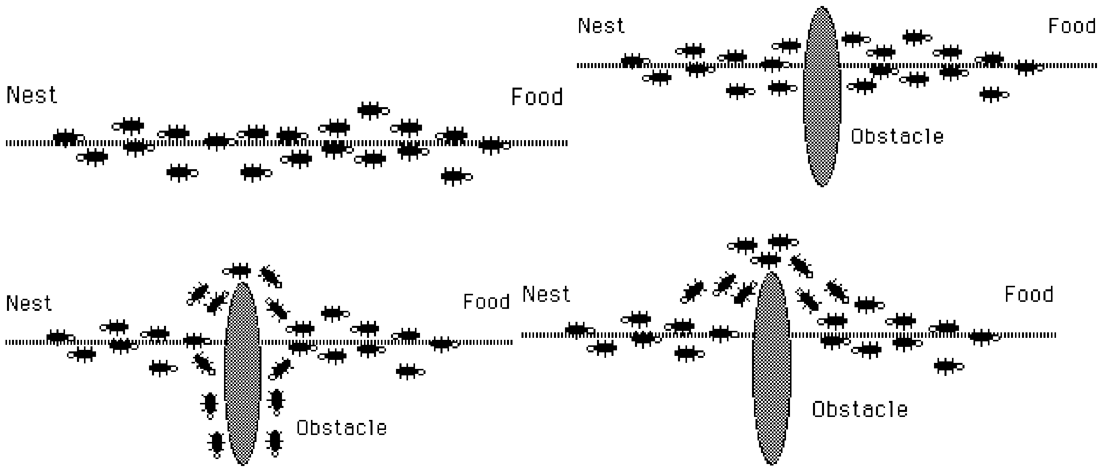

Figure 4-1: Behavior of real ants

4.2 Characteristics of proposed method

Positive Feedback

It reinforces good solution directly by pheromone accumulation.

Negative Feedback

It avoids premature convergence (stagnation) by pheromone evaporation.

Cooperation

It explores different solutions, where multiple ants are exploring solution space and pheromone trial reflecting multiple perspectives on the solution space.

4.3 Difference between real and artificial ants

Table 1 illustrates a comparison between the actual and fake ants to construct the ant colony optimization method.

Table 4-1: Analogy of Real and Artificial Ants

Sr.No.	**Real Ant**	**Artificial Ants**
1.	Ants move in their environment in an asynchronous way.	Ants are synchronized, where they follow the same path back to the nest at each iteration.
2.	The foraging behavior is based on an implicit evaluation of a solution, where the shorter paths will be completed earlier than longer ones.	They evaluate a solution on some quality measure which is used to determine the strength of pheromone strengthening that the ants perform during their return trip to the nest.
3.	They leave pheromone on the ground wherever they move.	They only deposit pheromone on their way back to the nest.

Source: Marco Dorigo and Thomas Stutzle (2004) “Ant Colony Optimization Handbook”, Massachusetts Institute of Technology, London, England.

4.4 Ant colony optimization algorithm

Ant Colony Optimization (ACO) is a meta-heuristic approach. A colony of artificial ants cooperates in finding best solutions to discrete optimization problems. Application of ACO algorithms to the arbitrary combinatorial optimization problem requires being projected on a graph (Dorigo and Gambardella 1997). Consider a graph ***G*** = ***(D,L,C)*** in which ***D***={ d_1, d_2 ...d_n}is the set of decision points at which some decisions are to be made, ***L***={ l_{ij} } is the set of options $j=1, 2,...,J$ at each of the decision points $i=1,2,...,n$ and finally ***C***= { c_{ij} } is the set of costs associated with options ***L***={ l_{ij} } . The components of sets D and L may be constrained if required. A path on the graph is called a solution (φ) and the minimum cost path on the graph is called the final optimal solution (φ*). The cost of a solution is signified by f(φ) and the ultimately the cost corosponding to the optimal solution is given by f(φ*).

The necessary steps on the ACO algorithms may be defined as follows (Dorigo M M. V., 1996):

1. m ants are randomly attached to the N decision points of the problem, and the amount of pheromone trail on all options is initialized to some proper value at the start
2. The second thing is a transition rule which is used by ant k at each decision point i to decide which option available is to be selected. Once the option at the current decision point is selected, the ant proceeds to the next decision point and the same process is followed by ants. The solution is incrementally created by ant k, as it moves from one point to the next one and so on. This procedure is repeated until all the decision points of the problem are not covered and ant k constructs a complete solution. The transition rule is defined as follows (Dorigo, 1996).

$$Pij(k,t) = \frac{\left\{\left[\tau_{ij(t)}\right]^{\alpha}\left|\left[\eta_{ij}\right]^{\beta}\right.\right\}}{\sum_{j=1}^{J}\left\{\left[\tau_{ij(t)}\right]^{\alpha}\left|\left[\eta_{ij}\right]^{\beta}\right.\right\}}$$

where p_{ij} (k ,t) is the probability that the ant k selects option l_{ij} (t) for the ith decision at iteration t; $\tau_{ij(t)}$ is the concentration of pheromone on option l_{ij} (t) at iteration t; $\eta_{ij} = 1/(c_{ij})$ is the heuristic value representing the cost of choosing option j at point i, and α and β are two parameters that control the relative weight of the pheromone trail and heuristic value referred to as pheromone and heuristic sensitivity parameter, respectively. The heuristic value η_{ij} is analogous to providing the ants with sight and is sometimes called visibility. This value is calculated once at the start of the algorithm and is not changed during the computation. The role of the parameters α andβ can be best described as follows. Ifα=0, the cheapest options are more likely to be selected leading to a classical stochastic greedy algorithm.

If on the contrary β=0, only pheromone amplification is at work, which will lead to the pre-mature convergence of the method to strongly sub-optimal solution (Dorigo, 1996).

3. The cost f(φ) corosponding to the trial solution that is generated, is calculated. And this is called a cycle of a complete trial solution.
4. The above Steps 2 and 3 are repeated for all m ants of the colony. And then at the end of which, m trial solutions are created, and their costs are calculated. Generation of m trial solution and the calculation of their corresponding costs is referred to as an iteration (t).
5. Then pheromone is updated at the end of each iteration as the given in the following general form of the pheromone updating formula (Dorigo, 1996).

$$\tau_{ij}(t+1) = \rho\tau_{ij}(t) + \Delta\tau_{ij}$$

Where $\tau_{ij}(t+1)$ is the amount of pheromone trail on option j of the ith decision point, i.e. option l_{ij}, at iteration t+1;$\tau_{ij}(t)$concentration of pheromone on option l_{ij} at iteration t; $0 \leq \rho \leq 1$ is the coefficient representing the pheromone evaporation and $\Delta\tau_{ij}$is the change in pheromone concentration associated with option l_{ij}. The amount of pheromone trail $\tau_{ij}(t)$associated with option l_{ij} is intended to represent the learned desirability of choosing option j when in decision point i. The pheromone trail information is changed during the problem solution to reflect the

> experience acquired by ants during problem solving. The main role of pheromone evaporation is to avoid stagnation, that is, the situation in which all ants end up doing the same tour. In addition, evaporation reduces the likelihood that high cost solutions will be selected in future cycles (AFSHAR, 2011).

The pheromone amount assigned to each of the options during a cycle is a function of the cost of the trial solution generated. The better the trial solution and hence the lower the cost. The larger the amount of pheromone added to the option. Consequently, solution components that are used by the best ant and form a part of the low cost solution receive more pheromone density and higher the probability to be selected by future ants. This choice clearly helps to direct the search towards good solutions (AFSHAR, 2011).

At the end of the iteration, each ant has produced a trial solution. The pheromone is updated before the next iteration starts. This process is continued until the iteration counter reaches its maximum value defined by the user. A note has to be added regarding the feasibility of the solutions created by ants unconstrained optimization problems. If the constraints can be explicitly defined regarding the options available at a decision point, the ants are forced to build feasible solutions by limiting the available options to those leading to possible solutions. In TSP, for which the ant algorithms are initially devised and tested in, the feasibility of the solution requires that each point is visited once and only once and that the finishing point is the as same as the starting one. This is not, however, possible on optimization problems such as pipe network optimization problems, where the constrained are implicitly defined regarding the options and, therefore, the feasibility of the solution is only known when the solution is entirely created. With these problems, a higher total cost is usually associated with the infeasible solutions via the use of a penalty function to discourage the ants to take options which constitute part of these solutions (AFSHAR, 2011).

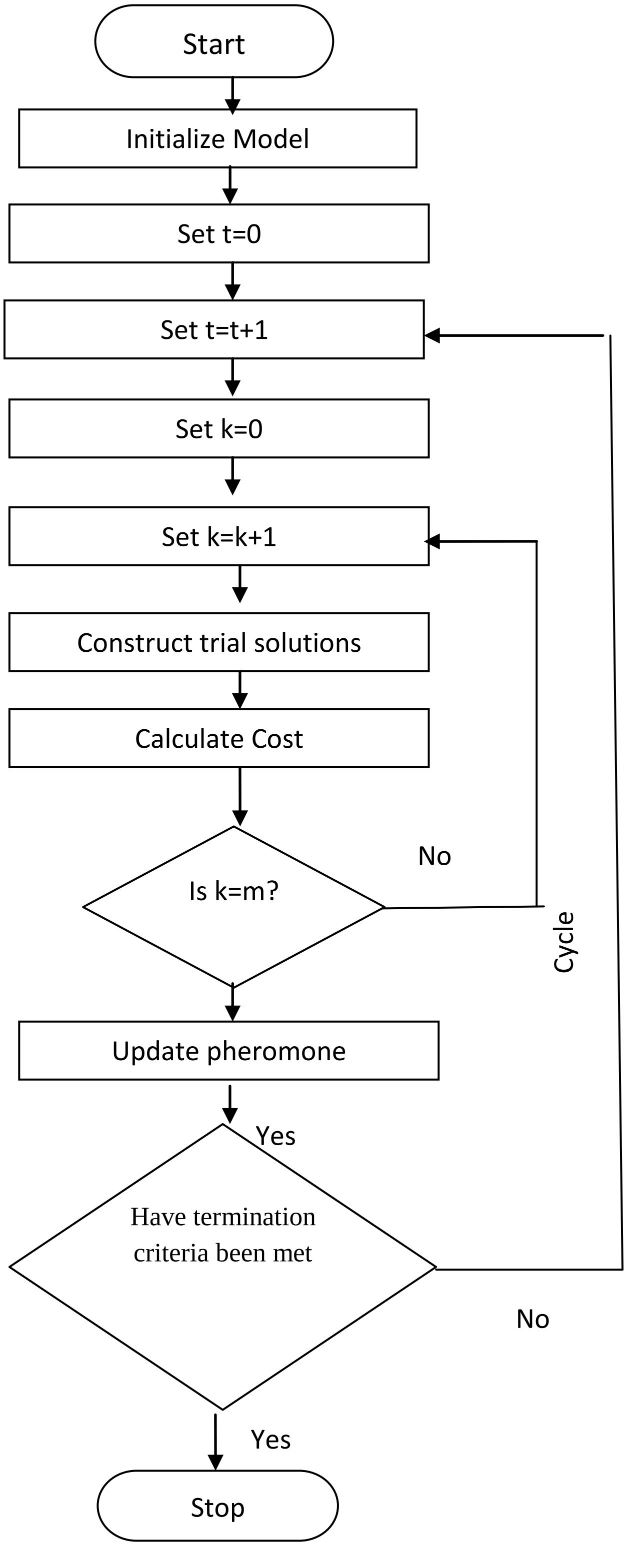

Figure 4-2: Generalized flowchart for ACO

4.5 Applications of ant colony optimization

Instances of ACO have been applied extensively to a variety of discrete combinatorial optimization problems like the Traveling Salesman Problem, the Quadratic Assignment Problem, the Network Communication Routing Problem, Vehicle Routing Problem, Job-Shop Scheduling, Sequential Ordering, Graph Coloring, Time Tabling, Shape Optimization, and so on.

Many researchers have applied ant colony optimization algorithm in various applications. Some of these requests are written below.

a) Network Reconfiguration.
b) System Restoration.
c) Network Routing.
d) Power Distribution Network.
e) Travelling Salesman Problem.
f) Graph Coloring.
g) Vehicle Routing.
h) Job Shop Scheduling.
i) Time Tabling.

The continuous allowable range of decision variables is discretized into a distinct set of allowable values, and a search is then conducted over the resulting discrete search space for the optimum solution (Abbaspour KC, 2001). The ant algorithm has been shown to outperform other general purpose heuristic search algorithms, including Gas for small-scale problems (Dorigo and Gambardella 1997). The performance of the method, however, deteriorates for problems of growing dimensions (Dorigo M M. V., 1996).

The problem of determining a minimum cost design of a multilevel branching storm sewer system is formulated by using a serial approach to describe the system and proceeding through the computational algorithm (Mays LW, 1976).

5 MATHEMATICAL MODEL

5.1 Basic optimization problem

The optimization problem can be expressed as follows:

Minimizes $y = f(X)$

Subjected to

$g_j(X) \leq 0, j = 1,2,.........m$

Where

$f(X)$ is objective function involving 'n' numbers of decision variables ($X_{1,} X_{2\,..........} X_n$),

$g_j(X)$ are constraints and m is total numbers of constraints.

In the present context, the objective function is the cost of the sewer system which is to be minimized subject to various constraints involving hydraulic, constructional and other considerations.

5.2 Objective function

The objective function or the cost of the sewer system is comprised of the cost of many items:

1. Cost of sewer pipes
2. Cost of earthwork
3. Cost of manhole

A synthetic approach may, however, associate the various costs into three major costs as described below:

1. **The cost of sewers** (pipes), which will include the cost of their transportation, join material, handle, etc. The cost of various items included in this head would be dependent on the size of the sewers only.

2. **The cost of earthwork**, which will include the cost of mainly digging, refilling, shattering, etc. This cost would be dependent primarily on the depth of excavation as well as on the size of the sewer.
3. **The cost of the manhole**, which will include the cost of providing complete manhole. This cost will also be dependent on the depth of excavation as well as the size of the sewer.

For a given link of the sewer system, the total cost of pipe can be determined by its size and total length. Similarly, the total cost of earthwork may be determined by the average depth of the link, sewer size, and its total length. The total cost of the manhole for a link would be dependent on total numbers of manholes on that link. The total cost of the system (value of the objective function) would be the sum of the above three costs for each link.

The total cost of a gravity system for a given layout may, therefore, be defined as a function of sewer size (D), depth of excavation at an upstream and depth of excavation at downstream. Better results are obtained when both the depth of excavation and the diameter are used as the independent variables (Onga, 1988).

5.2.1 Cost of Pipe

In the most of the sewer project the diameters are commercially fixed. A discrete set of pipe diameter is available as per the flow requirements.

The cost of pipe (COSTSW) can be calculated by the following mathematical formula

COSTSW=COSTSW+SD1

SD1 = SD1 + SDD * UCSW

SDD = SDD + LINEL

Where, the SD1 is the rate of sewer at different diameter, UCSW is the cost at different diameter, SDD is the total length of the sewer.

Providing at the site, lowering & laying in trenches, aligning & jointing of RCC pipes NP3 and NP4class (with s/s ends) as per IS: 458 - 2003 (amended up to date) at all depths for sewer lines as per IS: 5382 -1985with latest amendments till date.	Cost (₹)
For RCC NP-3 & NP-4 pipes	
200 mm dia RCC NP_3 pipe	518.00
250 mm dia RCC NP_3 pipe	724.00
300 mm dia RCC NP_3 pipe	973.00
350 mm dia RCC NP_3 pipe	1600.00
400 mm dia RCC NP_3 pipe	1850.00

Source: RUIDP Schedule of rates 2013

5.2.2 Cost of Earthwork

The earthwork is basically to dig out the soil upto a sufficient depth so that sewer can be arranged as per the design. The following relationship was obtained in respect of the cost of earthwork (COSTEX)

- If the depth of excavation is less than 1.5 meters
  COSTEX=COSTEX + (ERW*DEP_EX*203)
- If the depth of excavation lies between 1.5 to 3meter then
  COSTEX=COSTEX + (ERW*1.5*203) + (ERW*(DEP_EX-1.5)*233.5)

Earth work in excavations in foundation, trenches manholes, road side chambers, etc., including the dressing of sides and ramming of bottoms, including getting out the excavated material, refilling after laying pipe/ foundation and disposal of surplus excavated material at a lead up to 50m suitable site as per direction of Engineer for following depths, below natural ground / Road top level.Trench width payable as per width chart.	Cost (₹)
In all types soils such as moorum, sand, sandy silt, clay, black cotton soil, kankar, etc.	
> upto 1.5 m deep	203.00
>1.5m and upto3.0m deep	233.50
>3.0m and upto 4.5m deep	268.50
>4.5m and upto 6.0m deep	309.00
>6m deep and upto 7.5m deep	355.00
>7.5m deep	408.00

Source: RUIDP Schedule of rates 2013

5.2.3 Cost of Manhole

The following relationship was obtained in respect of the cost of earthwork (COSTMH)

COSTMH= SMH(1)*11800 + SMH(2)*23100 + SMH(3)*40000 + SMH(4)*54600

Where, SMH is the sum of no of manholes at different depth of excavation

S. No.	Manhole type	Cost(₹)
1.	Manhole "Type-A" of depth 0.90 m	11,800.00
2.	Manhole "Type-B" of depth 1.70 m	23,100.00
3.	Manhole "Type-C" of depth 2.60 m	40,000.00
4.	Manhole "Type-D" of depth > 2.60 m	54,600.00

Source: RUIDP Schedule of rates 2013

5.2.4 Total Cost

The total cost of ith link would be

$TCOST_i = COSTEX_i + COSTMH_i + COSTSW_i$

$TCOST_i$ = total cost of i^{th} sewer ; $COSTEX_i$ = cost of excavation fir i^{th} sewer pipe; $COSTMH_i$ =cost of manhole for i^{th} pipe; $COSTSW_i$= cost of sewer pipe for i^{th} pipe

Therefore, objective function f (X) for total N links

$$f(\mathrm{D, Depths, slope}) = \sum_{i=1}^{N} \{(TCOST_i)\}$$

5.3 Constraints

The design of a sewer system has to satisfy many constraints involving mainly hydraulic and other practical consideration.

5.3.1 Part Full Flow Constraint

The depth of flow in the sewer should not be more than its design value. For a given discharge, diameter and depth of flow there would be a unique value of the required slope (Sr). In other words, the actual slope of sewer should not be less than this designed required slope. The actual slope of i th link of length LG_i is given by:

$Slope_i = \{(GRLS – DEPTHS) – (GRLE – DEPTHE)\} / LG_i$

The constraints may be required as:

$Sr_i \geq Slope_i$

$Slope_i - Sr_i \leq 0$

$\{(GRLS – DEPTHS) – (GRLE – DEPTHE)\} / LG_i \leq 0$

5.3.2 Minimum Diameter Constraint

The diameter of a link should not be less than the prescribed minimum size (D_{min})

$D_i \geq D_{min}$

In which D_i = diameter of sewer link i

Dmin = minimum allowable diameter, taken as 200 mm in this work.

5.3.3 Diameter Progression Constraint:

In the flow passage the diameter of downstream sewer pipe should be greater or equal to the just upstream diameter.

$D_i \geq D_{i-1}$

in which D_{i-1}= diameter of wastewater link (i-1).

5.3.4 Minimum Velocity Constraint:

A minimum velocity is defined in the CPHEEO manual 1993 for the waste water flow in the sewer line. This is necessary to avoid anaerobically and settling of particles. The velocity of flow in the i^{th} link (V_i) should not be less than the defined minimum velocity (V_{min})

$V_i \geq V_{min}$

in which V_i = velocity in link i at peak flow;

and V_{min} =minimum allowable velocity at peak flow, taken as 0.6 m/s in this work.

V_i is a function of discharge (Q), slope and diameter of the sewer (D). The slope is a function of upstream and downstream depths as ground elevations are fixed.

5.3.5 Maximum Velocity Constraint:

For the reason of corrosion of sewer surface due to high velocity the velocity of flow in the i^{th} link (V_i) should not be greater than the defined maximum velocity (V_{max})

$V_i \leq V_{max}$

in which V_i = velocity in link i at peak flow;

and V_{max} = maximum allowable velocity, taken as 3.0 m/s in this work.

5.3.6 Minimum Cover Constraint:

There should be some minimum cover (C_{min}) over the buried sewer line to avoid damage to the sewer line.

$Depthe_i - Di \geq C_{min}$

Where $Depthe_i$ = depth of excavation at downstream of ith link, D_i = diameter of wastewater link I, C_{min} = minimum cover depth, assumed as 0.9 meters in this work.

5.3.7 Maximum Depth Constraint:

The depth of excavation should not exceed practical limits (depmax)

$Depthe_i \leq depmax$

Where $Depthe_i$ = depth of excavation at downstream of i^{th} link and depmax = maximum allowable wastewater line depth depending upon subsoil conditions, taken as 5 m in this work.

5.3.8 Invert levels

The invert level of ith link should also not be above the invert level of its previous link

$Depthe_i - D_i \leq depths_{i+1} - D_{i+1}$

in which $Depthe_i$ = depth of excavation at downstream of ith link

and $Depths_{i+1}$ = depth of excavation at upstream of i+1th link

5.3.9 Non Negativity Constraints

The values of decision variables diameter, depth of excavation at the upstream and the downstream level may not be negative, that is

- $D_i \leq 0$

- $\text{Depths} \leq 0$

- $\text{Depthe} \leq 0$

Due to constraints of minimum available or allowable commercial diameter and maximum / minimum soil covers which are positive, the above constraints may, however, be redundant.

5.4 Penalty function

A penalty method replaces a constrained optimization problem with a series of unconstrained problems whose solutions ideally converge to the solution of the original constrained problem. The unconstrained problems are formed by adding a term to the objective function that consists of a penalty parameter and a measure of violation of the constraints. The measure of violation is nonzero when the constraints are violated and is zero in the region where constraints are not violated.

In the present study, there are three conditions in which penalty can be assigned to the objective function

a. **Penalty due to depth:**

IF depth ≥ max. allowable depth then

PENDEP=PENDEP+PEN*(AVG-DEPMAX)

And $PEN = 0.5 \times 10^6$

b. **Penalty due to minimum velocity:**

PVEL ≤ minimum allowable velocity then

$PENV_{MIN} = PENV_{MIN} + PEN*(PV_{MIN} - PVEL)$

c. **Penalty due to maximum velocity:**

If $PVEL \geq PV_{MAX}$ then

$$PENV_{MAX}=PENV_{MAX}+PEN*(PVEL-PV_{MAX})$$

Hence the total penalty comes out to be the sum of all three penalties as:

$$PC=PENV_{MIN}+PENV_{MAX}+PENDEP$$

5.5 Overall expression

To sum up, the problem of optimization of a gravity main sewer line with ‘N’ number of links may be expressed as

Find D_i , $Depths_i$ and $Depthe_i$ ($i=1$ to N) Which minimizes,

$$f(\mathrm{D}, \mathrm{Depths}, \mathrm{Depthe}) = \sum_{i=1}^{N} \{(TCOST_i + PC)\}$$

Subject to constraints,

$$\left.\begin{array}{l}
g(1)_i = Slope_i - Sr_i \leq 0 \\
g(2)_i = D_{min} - D_i \leq 0 \\
g(3)_i = V_{min} - V_i \leq 0 \\
g(4)_i = V_i - V_{max} \leq 0 \\
g(5)_i = C_{min} - (Depthe_i - D_i) \leq 0 \\
g(6)_i = Depthe_i - depmax \leq 0 \\
g(7)_i = - D_i \leq 0 \\
g(8)_i = - Depths \leq 0 \\
g(9)_i = - Depthe \leq 0
\end{array}\right\} \text{For } i=1 \text{ to } N$$

$$\left.\begin{array}{l}
g(10)_i = D_{i-1} - D_i \leq 0 \\
g(11)_i = (Depthe_i - D_i) - (depths_{i+1} - D_{i+1}) \leq 0
\end{array}\right\} \text{For } i= 1 \text{ to } N-1$$

Hence, for a given N numbers of link the problem involves finding out three N variables subject to 9 N constraints.

6 COMPUTER PROGRAM

6.1 Fortran language

In this research, the proposed method (ACO) is coded using FORTRAN to solve the least-cost design and operation of sewerage system problem. By running this program, the optimal solution (best configuration) is obtained.

6.1.1 Introduction

One of the oldest programming languages, the FORTRAN was developed by a team of programmers at IBM led by John Backus and was first published in 1957. The name FORTRAN is an acronym for formula translation, because it was designed to allow easy translation of math formulas into code (Etter, 1990).

The FORTRAN programming language was one of the first (if not the first) “high level" languages developed for computers. It is referred to as a high-level language to contrast it with machine language or assembly language which communicates directly with the computer's processor with very primitive instructions. Since all that a computer can really understand are these primitive machine language instructions, a FORTRAN program must be translated into machine language by a special program called a FORTRAN compiler before it can be executed. Since the processors in various computers are not all the same, their machine languages are not all the same. For a variety of reasons, not all FORTRAN compilers are the same (McCracken, 1961) (Sleighthome & Chivers, 1990). For example, more recent FORTRAN compilers allow operations not allowed by earlier versions. In this research work Force 2.0 Compiler has been used for the execution of the program (Nyhoff, 1997).

It is still the major language of science and is heavily used in statistical computing. The most standard version of FORTRAN is referred to as Fortran 77 since it is based on a standard established in 1977. A new standard was developed in 1990 that incorporates some of the useful ideas from other languages, but we will restrict ourselves to Fortran 77 (Metcalf, 1985).

6.1.2 Concept of Feasible Diameter Sets

(Swarna and Modak, 1990) defined feasible diameter set for a link to the range or set of diameters that can satisfy hydraulic constraints such as velocity and partial depth of flow for a specified design flow.

The process of finding a feasible diameter set for a link involves finding out feasible slope for that link and comparing the same with minimum and maximum permissible slopes for each of the commercially available diameters. The Manning formula and continuity equation used for this purpose may be expressed as:

$$V = C_1\, D^{2/3}\, S^{1/2}$$

$$Q = C_2\, D^{8/3}\, S^{1/2}$$

Where,

C_1 and C_2 are constants dependent upon Manning’s Coefficient and depth of flow, whose values may be computed for a given depth of flow using relationships described in hydraulic formulae in chapter 3.

The feasible diameter set for a link is found with the following steps:

1. For each of the available commercial sewer size, find the minimum slope (S_{min}) from equation 6.1 based on prescribed minimum velocity. Similarly, maximum slope (S_{max}) may also be found for prescribed maximum velocity.
2. For specified design flow, find the feasible slope (S_f) for each of the commercially available size using Equation 6.2.
3. If feasible slope (S_f) of a particular size(s) falls between the value of maximum and minimum slopes (S_{max} and S_{min}) of that particular size, then that size would be feasible diameter and corresponding slope a feasible slope.

4. In fact, a size whose S_f is less than S_{min}, may also be a feasible size, provided at S_{min} velocity constraint is not violated. The depth of flow at S_{min} would, however, be less than the designed depth of flow.

6.2 Current approach:

The present work basically uses the computer program to fit the given problem of sewer system design optimization. A program was developed based on the concept of feasible diameter and slope set. The algorithm considers diameter and slope of the sewer as a discrete variable. The values taken as input for diameter and slope correspond to the commercially available diameter and slope.

A flow diagram of this program is given in the computation of various design factors can be accomplished with the help of hydraulic formula given in chapter 3. The refinement of optimal design generation also incorporates changing various design factors easily.

Since the program involves numerous calculation of function, the gradient of a function, checking of the constraints, etc., comparatively long time is taken to reach to an optimal solution (if more number of iterations are required for optimal).

6.2.1 Flow chart for Analysis of Sewerage System

1. Start with the first link (I=1) of the first iteration (ITN=1)
2. Calculate constant value ‘CK
3. Calculate values of Hydraulic Mean Depth (PHMD), Velocity (PVEL), Depth of flow (DEPTH) and Discharge (PQ) in partial flow condition.
4. Calculate invert levels of upstream and downstream node of a particular link
5. Calculate no of manholes, depth of excavation and earthwork.
6. Calculate cost of sewer (COSTSW), cost of manholes (COSTMH), cost of earthwork (COSTEX)
7. Calculate the total cost of the sewer system (TCOST)
8. Add the respective penalty cost (PENDEP, PENVMAX and PENVMIN) in TCOST where constraints are violated.

    a. If the depth of excavation > DEPMAX, then add PENDEP in TCOST
    b. If velocity > VMAX, then add PENVMAX in TCOST
    c. If velocity < VMIN and discharge (PQ) > minimum discharge (PQ min), then add PENVMIN in TCOST

9. Calculate feasible solution using ACO.
10. Take output, check if the solutions obtained is feasible or not
    a. If feasible solution, not obtained increase ITN by 1 and go to step 1
    b. If feasible solution obtained, then take the output and end.

The basic procedure outlined above may be implemented with the following steps

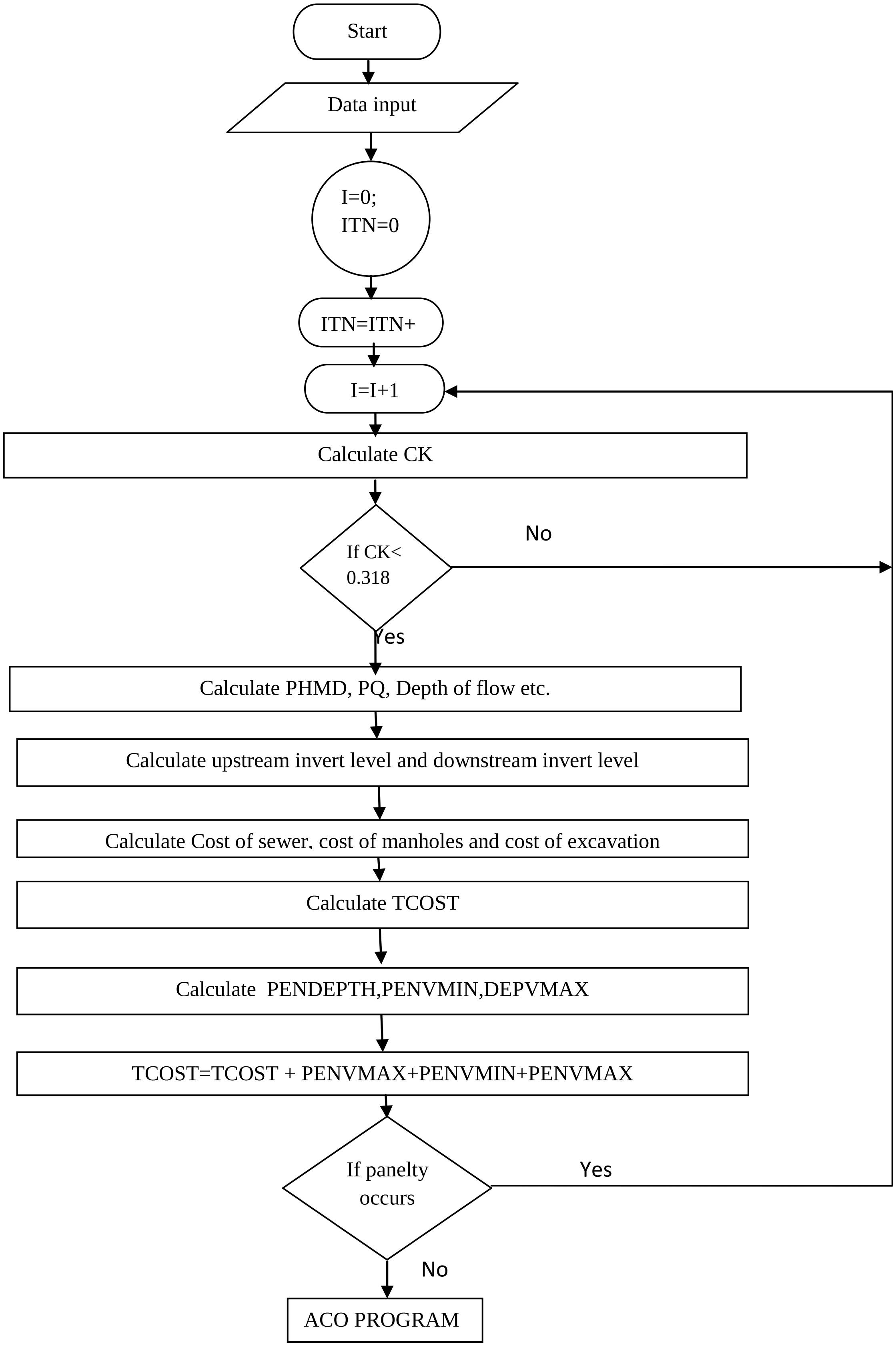
Start
Data input
I=0;
ITN=0
ITN=ITN+
I=I+1
Calculate CK
If CK<
0.318
No
Yes
Calculate PHMD, PQ, Depth of flow etc.
Calculate upstream invert level and downstream invert level
Calculate Cost of sewer, cost of manholes and cost of excavation
Calculate TCOST
Calculate PENDEPTH,PENVMIN,DEPVMAX
TCOST=TCOST + PENVMAX+PENVMIN+PENVMAX
If panelty
occurs
Yes
No
ACO PROGRAM

Figure 6-1: flowchart for analysis of sewerage system

6.2.2 Flow chart steps in Ant Colony Optimization

Initialization

1. Set iteration counter ITN =1
2. Pheromone intensity τ_e on each edge e=1
3. Initialize the model by initializing the Ant colony parameters
    a. α =1; the parameter controlling relative importance of pheromone intensity
    b. IANTIN=1000; the initial no. of ants
    c. β =0; the parameter controlling the local heuristics
    d. ρ = 1; the parameter of pheromone persistence
    e. λ = 1000; fraction of initial no. of ants used for t>1
    f. Δ; no. of best ants used for pheromone updating
4. Initial no of ants are placed at first pipe
5. Probability is calculated for t=1 as

$$Pe = \frac{\left\{\left[\tau_{e(t)}\right]^{\alpha}\left|\left[\eta_e\right]^{\beta}\right.\right\}}{\sum_{i=1}^{i+1}\left\{\left[\tau_{j(t)}\right]^{\alpha}\left|\left[\eta_j\right]^{\beta}\right.\right\}}$$

6. K is set to 1
7. The solution of first ant trial is generated
8. Trial cost for the first ant is calculated from the 'analysis of sewerage system algorithm'
9. Check if k=A
10. If no then k=k+1 and goto step 7
11. Record the least cost solution out of A

Pheromone Updating:

12. Each of the links participating at the *i*th best solution (i is the subset Δ) is added a pheromone amount equal to:

$$\mathrm{ph_i} = \mathrm{Cost_{max}}/\mathrm{Cost_i}$$

Where, $\mathrm{Cost_{max}}$ is the highest cost among the bestset (i.e.,Δ) of ants, $\mathrm{Cost_i}$ is the solution cost of the current *i*thbest solution (i is from the subset Δ).

Using this mechanism links that participated at lower solutions will receive a higher pheromone quantity, i.e., their likelihood to be chosen at subsequent iterations will increase

Probability updating:

13. Update the links outgoing probabilities out of node j:

$$\mathrm{p_i} = \frac{\mathrm{ph_i}}{\sum_{\mathrm{i=1}}^{\mathrm{N_j}} \mathrm{ph_i}}$$

Where: p_i = probability of choosing link i

N_j= number of links out of node j

ph_i = pheromone amount on link i

Iterate:

14. Go back to step 2 with a fraction $\lambda$of the initial number of ants A (i.e. λA), while keeping the best solution

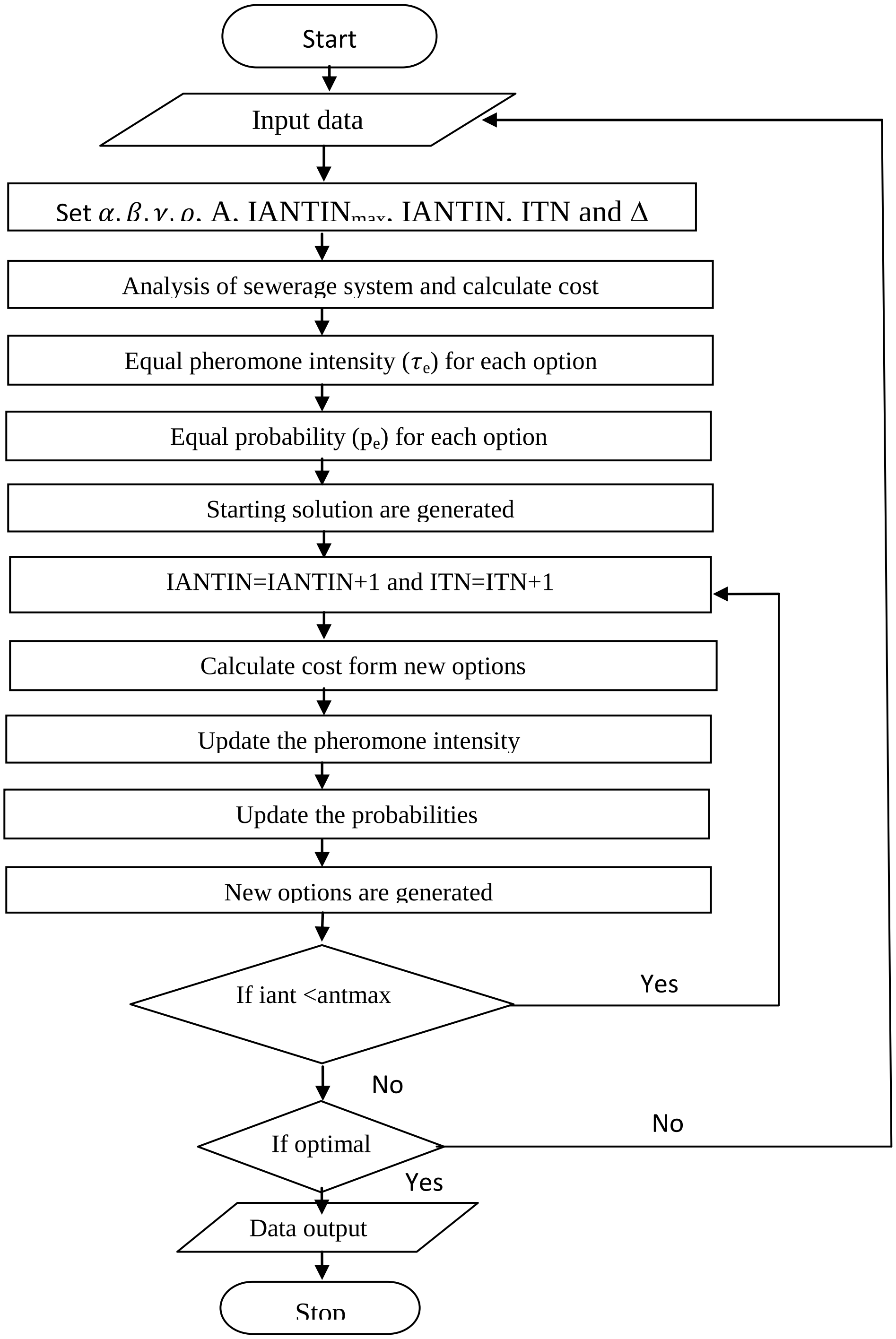

Figure 6-2: flowchart for ACO

7 RESULT AND DISCUSSION

- The algorithm developed in this work can be employed to solve several hypothetical as well as real life problems as a part of validation and testing of the program developed.
- The data of various design parameters like Link no, u/s node, d/s node, length of each link, discharge in each link, u/s ground level, and d/s ground level are given in Table 7.1
- The total number of commercially available diameters and slope are given in Table 7.2
- Maximum and minimum permissible velocities, Manning's coefficient, Total no. of links, Minimum prescribed cover and maximum allowable depth, Minimum discharge, Total no. of iteration, Earthwork factor (EW) are given in Table 7.3

Table 7-1: Input Data

S. No	Link No.	Upstream Node	Downstream Node	Length (m)	Discharge (lps)	Upstream ground level (m)	Downstream ground level (m)
1.	51	51	52	101	3.17234	346.27	344.79
2.	52	53	54	25	0.71534	345.15	345.09
3.	53	55	54	16	0.43543	345.12	345.09
4.	54	54	52	33	2.11665	345.09	344.79
5.	55	52	56	25	6.13267	344.79	344.68
6.	56	57	58	33	1.08976	345.35	346.4
7.	57	59	58	24	0.6276	346.45	346.4
8.	58	58	60	45	3.05043	346.4	345.75
9.	59	61	62	18	0.52965	347.54	347.12
10.	60	63	62	22	0.77821	348.65	347.12
11.	61	62	60	37	2.42876	347.12	345.75

12.	62	64	60	35	0.9343	346.22	345.75
13.	63	60	65	46	7.65763	345.75	345.45
14.	64	66	65	50	1.71217	346.87	345.45
15.	65	65	56	48	10.70843	345.45	344.68
16.	66	56	67	12	17.4365	344.68	344.52
17.	67	68	69	32	0.96567	350.65	349.81
18.	68	70	69	25	0.74714	351.08	349.81
19.	69	69	71	31	2.64603	349.81	348.58
20.	70	72	71	19	0.40465	348.67	348.58
21.	71	71	73	21	3.7312	348.58	348.36
22.	72	74	75	140	4.48257	351.33	349.02
23.	73	76	75	24	0.74735	348.1	349.02
24.	74	75	73	26	6.00876	349.02	348.36
25.	75	77	73	109	3.29989	349.57	348.36
26.	76	73	78	41	14.53765	348.36	345.23
27.	77	79	78	16	0.43523	345.26	345.23
28.	78	78	80	17	15.50265	345.23	344.87
29.	79	81	80	19	0.59137	346.25	344.87
30.	80	80	67	39	17.09076	344.87	344.52
31.	81	82	67	28	0.96587	344.93	344.52
32.	82	67	83	55	37.0454	344.52	344.35
33.	83	84	85	31	1.15187	353.28	352.07
34.	84	86	85	15	0.40445	352.14	352.07
35.	85	85	87	38	2.70879	352.07	350.78
36.	86	88	87	33	0.9376	351.2	350.78
37.	87	87	89	31	4.76236	350.78	349.79
38.	88	90	91	14	0.52976	350.67	350.02
39.	89	92	91	18	0.49843	350.13	350.02
40.	90	91	96	35	2.14798	350.02	349.4

41.	91	93	89	29	0.80914	351.87	349.79
42.	92	89	96	23	6.31976	349.79	349.44
43.	93	94	96	17	0.43584	350.41	349.44
44.	94	96	95	15	9.24517	349.44	349.1
45.	95	97	95	12	0.52949	349.27	349.1
46.	96	95	98	19	10.17952	349.1	349.02
47.	97	99	98	34	1.21416	350.64	349.02
48.	98	98	100	35	12.4431	349.02	348.6
49.	99	101	100	19	0.52954	349.02	348.6
50.	100	100	102	63	14.88058	348.6	347.68
51.	101	103	104	38	1.21416	348.82	348.32
52.	102	105	104	14	0.52959	348.35	348.32
53.	103	106	104	26	0.87198	348.41	348.32
54.	104	104	102	32	3.57943	348.32	347.68
55.	105	102	107	17	19.02065	347.68	347.15
56.	106	108	107	34	1.02727	347.86	347.15
57.	107	107	109	46	21.44856	347.15	346.02
58.	108	110	111	35	1.15119	351.14	350.64
59.	109	112	111	64	2.11676	352.57	350.64
60.	110	111	113	78	5.54143	350.64	347.58
61.	111	114	113	21	0.71578	347.74	347.58
62.	112	113	109	38	7.40829	347.58	346.02
63.	113	109	115	45	30.35128	346.02	345.04
64.	114	116	117	18	0.59157	346.17	345.98
65.	115	118	117	24	0.84068	346.57	345.98
66.	116	117	119	29	2.30359	345.98	345.65
67.	117	120	119	16	0.59129	345.87	345.65
68.	118	119	115	35	4.0487	345.65	345.04
69.	119	121	115	43	1.27669	345.65	345.04

70.	120	115	122	48	37.13869	345.04	344.39
71.	121	123	122	35	1.02729	345.65	344.39
72.	122	122	124	27	39.03793	344.39	344.26
73.	123	127	126	16	0.31274	346.6	346.56
74.	124	125	126	19	0.49858	347.25	346.56
75.	125	126	128	14	1.33890	346.56	344.71
76.	126	129	128	18	0.46617	344.79	344.71
77.	127	128	124	36	2.73965	344.71	344.26
78.	128	124	183	29	42.67981	344.26	344.35
79.	129	130	131	17	0.43553	346.7	346.19
80.	130	132	131	13	0.43585	346.23	346.19
81.	131	131	133	28	1.52517	346.19	346.34
82.	132	134	133	20	0.68418	346.54	346.34
83.	133	133	135	17	2.61417	346.34	346.11
84.	134	136	135	22	0.80917	345.9	346.11
85.	135	135	137	37	4.3538	346.11	344.98
86.	136	138	137	11	0.49818	345.65	344.98
87.	137	137	139	23	5.72738	344.98	344.67
88.	138	140	139	27	0.62228	344.86	344.67
89.	139	139	183	31	7.40838	344.67	344.35
90.	140	183	141	49	88.4039	344.35	344.08
91.	141	141	142	86	91.08648	344.08	343.84
92.	142	143	142	33	1.15167	343.92	343.84
93.	143	142	144	38	93.20359	343.84	343.8
94.	144	145	144	36	0.96578	343.98	343.8
95.	145	144	146	13	94.6398	343.8	343.79
96.	146	147	148	28	0.84043	347.23	346.64
97.	147	149	148	24	0.62235	346.7	346.64
98.	148	148	150	29	2.08556	346.64	346.36

99.	149	151	150	25	0.65323	346.46	346.36
100.	150	150	146	108	6.070345	346.36	343.79

Table 7-2: Commercially Available Diameters and Slopes

S. No.	Available Diameters	S. No.	Slopes Considered
1.	200	1.	50
2.	250	2.	100
3.	300	3.	150
4.	350	4.	200
5.	400	5.	250
		6.	300
		7.	350
		8.	400
		9.	450
		10.	500
		11.	550
		12.	600
		13.	650
		14.	700
		15.	750
		16.	800
		17.	850
		18.	900
		19.	950
		20.	1000
		21.	1050
		22.	1100
		23.	1150
		24.	1200

Table 7-3: Input Data for Sewer Design

Sr no.	PARAMETERS	VALUES
1.	Maximum permissible velocity	3.0 m/s
2.	minimum permissible velocity	0.6 m/s
3.	Manning’s coefficient	0.013
4.	Total no. of links	100
5.	Minimum prescribed cover	0.9 m
6.	Maximum permissible depth	5 m
7.	Minimum discharge	0.001
8.	Total no. of iteration	1000
9.	Earthwork factor (EW)	0.25 m

7.1 Results

This ACO program for sewer optimization took about 10 minutes of CPU time to reach to the final optimal solution using the ACO method on a PC. The resulting exhibit a final total cost of ₹73.67 lakh with discrete diameter and slope.

Comparison of the design review of conventional and optimal design is presented in Table 7.4. The results indicate a cost reduction in optimal design due to a decrease in both sizes of the sewer as well as in excavation.

The final optimal solution table is presented in table 7.5.

Table 7-4: Comparison Between Starting Solution and Optimal Sewer Design

S. NO.	**Link No.**	**Starting Sewer design**			**Optimal design using GA**		
		Dia (mm)	**Slope (1 in)**	**Dep_ex(m)**	**Dia (mm)**	**Slope (1 in)**	**Dep_ex (m)**
1.	51	350	50	1.73	300	50	1.68
2.	52	400	250	1.64	350	100	1.66
3.	53	250	200	1.49	200	200	1.44
4.	54	400	150	1.66	200	200	1.69
5.	55	250	150	1.92	200	200	1.85
6.	56	250	200	2.08	200	1200	1.96
7.	57	350	100	1.66	200	150	1.47
8.	58	350	100	2.58	200	150	2.32
9.	59	350	100	1.69	200	50	1.45
10.	60	350	100	2.22	200	50	1.96
11.	61	400	50	1.93	200	50	1.73
12.	62	350	50	1.68	200	100	1.48
13.	63	250	50	2.79	200	50	2.46
14.	64	250	750	2.15	200	50	1.63
15.	65	200	800	2.75	200	350	2.45
16.	66	200	650	2.32	200	1200	2.06
17.	67	400	100	1.88	200	50	1.52
18.	68	200	150	1.97	200	150	1.97
19.	69	400	100	2.08	200	100	1.88
20.	70	200	100	1.47	200	100	1.47
21.	71	300	100	1.61	200	100	1.51
22.	72	350	50	1.81	200	50	1.66
23.	73	200	1000	1.89	200	800	1.89
24.	74	200	50	2.29	200	50	2.3
25.	75	400	400	2.09	200	100	1.48
26.	76	250	1150	3.02	200	50	2.57
27.	77	200	350	1.43	200	400	1.42
28.	78	400	500	1.78	200	600	1.59

29.	79	400	250	2.27	300	50	2.02
30.	80	400	100	1.64	350	100	1.55
31.	81	400	250	1.77	300	50	1.59
32.	82	250	750	2.21	200	1000	1.93
33.	83	400	250	2.16	300	50	1.81
34.	84	400	250	1.62	300	50	1.63
35.	85	400	250	2.19	300	50	1.78
36.	86	350	550	1.75	200	100	1.46
37.	87	400	250	2.05	300	50	1.7
38.	88	400	250	1.92	300	50	1.7
39.	89	400	900	1.66	200	1200	1.47
40.	90	400	250	1.84	300	50	1.58
41.	91	400	250	2.6	300	50	2.27
42.	92	400	900	1.78	200	100	1.48
43.	93	400	50	1.93	250	50	1.78
44.	94	350	400	1.72	250	100	1.56
45.	95	350	550	1.64	250	50	1.5
46.	96	300	150	1.59	300	250	1.54
47.	97	300	450	2.29	200	50	1.89
48.	98	400	500	1.79	200	350	1.58
49.	99	400	900	1.82	250	50	1.49
50.	100	300	350	1.89	200	50	1.64
51.	101	400	350	1.82	200	150	1.54
52.	102	350	300	1.58	200	400	1.42
53.	103	350	100	1.65	300	200	1.54
54.	104	400	250	1.88	250	50	1.56
55.	105	400	950	1.88	300	100	1.7
56.	106	400	900	1.96	250	50	1.48
57.	107	400	900	2.16	250	50	1.57
58.	108	400	50	1.72	250	50	1.57
59.	109	350	450	2.46	250	50	1.79
60.	110	300	400	2.95	200	50	2.17
61.	111	350	950	1.64	200	150	1.43
62.	112	250	50	1.87	250	50	1.87
63.	113	250	650	1.93	200	50	1.46

64.	114	400	550	1.7	250	50	1.55
65.	115	400	50	1.67	250	50	1.52
66.	116	400	250	1.73	250	100	1.62
67.	117	400	850	1.72	250	50	1.52
68.	118	300	200	1.74	250	100	1.6
69.	119	350	600	1.84	250	50	1.59
70.	120	350	700	1.86	250	100	1.63
71.	121	400	900	2.23	250	50	1.75
72.	122	400	900	1.67	300	350	1.55
73.	123	350	100	1.63	250	100	1.53
74.	124	250	100	1.72	250	50	1.62
75.	125	350	300	2.47	250	50	2.25
76.	126	350	800	1.6	300	350	1.53
77.	127	400	900	1.82	250	100	1.51
78.	128	350	750	1.68	200	800	1.58
79.	129	250	650	1.71	200	50	1.5
80.	130	350	1150	1.58	200	250	1.43
81.	131	200	200	1.71	200	1150	1.52
82.	132	250	150	1.5	200	100	1.42
83.	133	400	100	1.83	200	150	1.55
84.	134	300	100	1.73	200	100	1.63
85.	135	300	50	1.75	200	50	1.65
86.	136	300	50	1.74	200	50	1.64
87.	137	200	50	1.63	200	50	1.53
88.	138	300	50	1.69	200	50	1.59
89.	139	200	950	1.73	200	350	1.65
90.	140	250	850	1.58	200	300	1.47
91.	141	400	50	2.21	200	200	1.51
92.	142	300	150	1.59	200	150	1.49
93.	143	350	150	3.06	200	200	1.68
94.	144	350	150	1.6	200	200	1.42
95.	145	250	200	3.19	200	150	1.8
96.	146	200	200	1.64	200	50	1.43
97.	147	350	550	1.58	200	300	1.43
98.	148	250	350	1.57	200	250	1.5

99.	149	300	300	1.53	200	300	1.43
100.	150	350	150	2.49	200	50	1.62
		Tcost (₹)	**1,14,95,767**		**Tcost**	**73,67,083**	

Table 7-5: Output Data for The Optimal Iteration

S. No.	**Slope (1 in)**	**DIA (mm)**	**QA (m^3/s)**	**THETA**	**DR**	**DEPTH (m)**	**PAREA (m^2)**	**PVEL (m/s)**	**PQ (m^3/s)**	**ILUS (m)**	**ILDS (m)**
1	50	300	0.13411	4.36579	0.78729	0.23619	0.0597	2.20695	0.13175	345.05	343.25
2	100	350	0.13373	4.13735	0.73878	0.25857	0.0762	1.71731	0.13086	343.88	343.63
3	200	200	0.00599	2.55924	0.35646	0.07129	0.01005	0.62961	0.00633	344	343.92
4	200	200	0.00561	2.50927	0.34454	0.06891	0.00959	0.61855	0.00593	343.63	343.465
5	200	200	0.00523	2.45736	0.33226	0.06645	0.00913	0.60681	0.00554	343.25	343.125
6	1200	200	0.00034	1.47989	0.13075	0.02615	0.00242	0.14346	0.00035	344.23	344.2025
7	150	200	0.00433	2.23056	0.28004	0.05601	0.0072	0.63832	0.0046	345.33	345.17
8	150	200	0.00361	2.11835	0.2552	0.05104	0.00632	0.60576	0.00383	344.2025	343.9025
9	50	200	0.00338	1.78771	0.18679	0.03736	0.00406	0.87401	0.00354	346.36	346
10	50	200	0.003	1.73101	0.17587	0.03517	0.00372	0.8429	0.00313	346.44	346
11	50	200	0.00262	1.66915	0.16425	0.03285	0.00337	0.80869	0.00273	345.37	344.63
12	100	200	0.00224	1.75663	0.18077	0.03615	0.00387	0.60598	0.00234	344.98	344.63
13	50	200	0.00186	1.52366	0.13821	0.02764	0.00262	0.72741	0.00191	343.9025	342.9825
14	50	200	0.0011	1.32736	0.10614	0.02123	0.00178	0.61678	0.0011	345.33	344.33
15	350	200	0.00076	1.55545	0.14374	0.02875	0.00278	0.28168	0.00078	342.9825	342.84536
16	1200	200	0.00038	1.52401	0.13827	0.02765	0.00263	0.14852	0.00039	342.84536	342.83536
17	50	200	0.00466	1.95173	0.21977	0.04395	0.00512	0.96241	0.00492	349.33	348.69
18	150	200	0.00428	2.22316	0.27838	0.05568	0.00714	0.6362	0.00454	348.85667	348.69
19	100	200	0.00349	1.98298	0.22628	0.04526	0.00533	0.69221	0.00369	347.77	347.46
20	100	200	0.00311	1.9209	0.21342	0.04268	0.00491	0.66892	0.00328	347.55	347.36
21	100	200	0.00273	1.85355	0.19979	0.03996	0.00447	0.64333	0.00287	347.36	347.15
22	50	200	0.00235	1.62131	0.15549	0.0311	0.00311	0.78208	0.00243	350.21	347.41
23	800	200	0.00038	1.44466	0.12487	0.02497	0.00226	0.17074	0.00039	346.98	346.95
24	50	200	0.00193	1.53864	0.14081	0.02816	0.0027	0.73582	0.00198	346.95	346.43

25	100	200	0.00133	1.52817	0.13899	0.0278	0.00265	0.51615	0.00137	348.33	347.24
26	50	200	0.00113	1.33671	0.10758	0.02152	0.00182	0.62205	0.00113	344.93	344.11
27	400	200	0.00056	1.4604	0.12748	0.0255	0.00233	0.2446	0.00057	344.14	344.1
28	600	200	0.00038	1.39114	0.11616	0.02323	0.00204	0.18844	0.00038	343.77833	343.75
29	50	300	0.12736	4.18247	0.74863	0.22459	0.05676	2.1959	0.12464	344.03	343.65
30	100	350	0.12698	4.00687	0.70963	0.24837	0.07301	1.70509	0.12449	343.64	343.25
31	50	300	0.1266	4.16486	0.7448	0.22344	0.05646	2.19432	0.12389	343.71	343.15
32	1000	200	0.00038	1.48774	0.13207	0.02641	0.00246	0.15814	0.00039	342.83536	342.78036
33	50	300	0.12608	4.15304	0.74222	0.22267	0.05626	2.19322	0.12338	351.47	350.85
34	50	300	0.12583	4.14742	0.74099	0.2223	0.05616	2.19268	0.12314	350.92	350.62
35	50	300	0.12539	4.13763	0.73884	0.22165	0.05599	2.19171	0.12272	350.32	349.56
36	100	200	0.00051	1.18961	0.08587	0.01717	0.00131	0.3813	0.0005	349.99	349.66
37	50	300	0.12506	4.13035	0.73724	0.22117	0.05586	2.19098	0.1224	349.19	348.57
38	50	300	0.12382	4.10357	0.73133	0.2194	0.05539	2.18814	0.12121	349.08	348.8
39	1200	200	0.00091	1.92806	0.21489	0.04298	0.00496	0.19388	0.00096	348.915	348.9
40	50	300	0.12344	4.09551	0.72954	0.21886	0.05525	2.18724	0.12085	348.8	348.1
41	50	300	0.12287	4.08356	0.72688	0.21806	0.05504	2.18587	0.12031	349.15	348.57
42	100	200	0.00051	1.18961	0.08587	0.01717	0.00131	0.3813	0.0005	348.55	348.32
43	50	250	0.05701	3.55643	0.60297	0.15074	0.03093	1.84365	0.05703	348.61	348.27
44	100	250	0.056	4.2166	0.756	0.189	0.03981	1.37694	0.05482	348.08	347.93
45	50	250	0.05454	3.49263	0.58731	0.14683	0.02997	1.82721	0.05477	348.1	347.86
46	250	300	0.05361	4.02301	0.71329	0.21399	0.05394	0.97416	0.05255	347.86	347.784
47	50	200	0.00057	1.11953	0.07631	0.01526	0.0011	0.50004	0.00055	348.58	347.9
48	350	200	0.00061	1.46763	0.12869	0.02574	0.00236	0.26302	0.00062	347.58	347.48
49	50	250	0.0518	3.42211	0.5699	0.14247	0.0289	1.80771	0.05224	347.81	347.43
50	50	200	0.00139	1.41113	0.11938	0.02388	0.00212	0.66404	0.00141	347.43	346.17
51	150	200	0.00109	1.52968	0.13925	0.02785	0.00265	0.42193	0.00112	347.45333	347.2
52	400	200	0.00067	1.53121	0.13952	0.0279	0.00266	0.25868	0.00069	347.23	347.195
53	200	300	0.06548	4.27268	0.76794	0.23038	0.05825	1.10127	0.06415	347.19	347.06
54	50	250	0.0651	3.7708	0.65472	0.16368	0.03406	1.89049	0.06438	347.06	346.42
55	100	300	0.06472	3.5377	0.59838	0.17951	0.04414	1.46821	0.06481	346.1	345.93
56	50	250	0.06444	3.7528	0.65044	0.16261	0.0338	1.88706	0.06379	346.66	345.98
57	50	250	0.06416	3.7452	0.64862	0.16216	0.03369	1.88558	0.06353	345.77	344.85
58	50	250	0.0638	3.73546	0.6463	0.16157	0.03355	1.88366	0.06321	349.97	349.27
59	50	250	0.06347	3.72656	0.64417	0.16104	0.03343	1.88188	0.06291	350.75	349.47

60	50	200	0.00114	1.33979	0.10806	0.02161	0.00183	0.62379	0.00114	348.02	346.46
61	150	200	0.00057	1.29051	0.10053	0.02011	0.00165	0.34409	0.00057	346.6	346.46
62	50	250	0.06296	3.71286	0.64088	0.16022	0.03323	1.8791	0.06244	345.61	344.85
63	50	200	0.00096	1.28114	0.09912	0.01982	0.00161	0.59071	0.00095	344.82	343.92
64	50	250	0.06157	3.6758	0.63197	0.15799	0.0327	1.87133	0.06118	345	344.64
65	50	250	0.06109	3.66309	0.6289	0.15723	0.03251	1.86857	0.06075	345.29	344.81
66	100	250	0.06061	4.63733	0.84004	0.21001	0.04402	1.38181	0.06083	344.64	344.35
67	50	250	0.05918	3.61289	0.61674	0.15418	0.03177	1.85724	0.05901	344.7	344.38
68	100	250	0.05879	4.40317	0.79489	0.19872	0.04184	1.3828	0.05786	344.22	343.87
69	50	250	0.05317	3.45736	0.57861	0.14465	0.02944	1.81763	0.05351	344.48	343.62
70	100	250	0.05304	4.06508	0.72275	0.18069	0.03799	1.36753	0.05195	343.62	343.14
71	50	250	0.05266	3.44423	0.57537	0.14384	0.02924	1.81398	0.05303	343.92	343.22
72	350	300	0.05228	4.54595	0.82294	0.24688	0.06224	0.83484	0.05196	343.11714	343.04
73	100	250	0.0519	4.01278	0.71097	0.17774	0.03733	1.36329	0.05089	345.43	345.27
74	50	250	0.05152	3.4149	0.56812	0.14203	0.02879	1.80564	0.05198	345.77	345.39
75	50	250	0.05114	3.40512	0.56569	0.14142	0.02864	1.80281	0.05163	343.82	343.54
76	350	300	0.05076	4.37202	0.78857	0.23657	0.05979	0.83423	0.04988	343.54143	343.49
77	100	250	0.05038	3.94644	0.69582	0.17396	0.03646	1.35715	0.04948	343.45	343.09
78	800	200	0.00126	1.99451	0.22869	0.04574	0.00541	0.24625	0.00133	343.04	343.00375
79	50	200	0.00084	1.23749	0.0927	0.01854	0.00146	0.56613	0.00083	345.41	345.07
80	250	200	0.00084	1.52761	0.1389	0.02778	0.00264	0.3263	0.00086	345.11	345.058
81	1150	200	0.00046	1.59424	0.15062	0.03012	0.00297	0.15992	0.00048	345.058	345.03365
82	100	200	0.00117	1.4773	0.13031	0.02606	0.00241	0.49592	0.00119	345.42	345.22
83	150	200	0.00455	2.26249	0.28723	0.05745	0.00746	0.64738	0.00483	345.03365	344.92032
84	100	200	0.00304	1.90893	0.21098	0.0422	0.00483	0.66439	0.00321	344.78	344.56
85	50	200	0.00266	1.67594	0.16551	0.0331	0.00341	0.81246	0.00277	344.56	343.82
86	50	200	0.00228	1.60829	0.15314	0.03063	0.00304	0.77482	0.00236	344.08	343.86
87	50	200	0.0019	1.53227	0.1397	0.02794	0.00267	0.73225	0.00195	343.82	343.36
88	50	200	0.00152	1.44466	0.12487	0.02497	0.00226	0.68295	0.00155	343.74	343.2
89	350	200	0.00114	1.73352	0.17635	0.03527	0.00373	0.31911	0.00119	343.2	343.11143
90	300	200	0.00076	1.52401	0.13827	0.02765	0.00263	0.29705	0.00078	343.12333	342.96
91	200	200	0.00523	2.45736	0.33226	0.06645	0.00913	0.60681	0.00554	342.96	342.53
92	150	200	0.00489	2.31001	0.29804	0.05961	0.00786	0.66071	0.00519	342.8	342.58
93	200	200	0.00604	2.56569	0.35801	0.0716	0.01011	0.63102	0.00638	342.53	342.34
94	200	200	0.00591	2.54887	0.35398	0.0708	0.00995	0.62734	0.00624	342.86	342.68

95	150	200	0.00553	2.39433	0.3175	0.0635	0.00857	0.68384	0.00586	342.34	342.25333
96	50	200	0.00118	1.35191	0.10994	0.02199	0.00188	0.63063	0.00118	346.08	345.52
97	300	200	0.00107	1.66931	0.16428	0.03286	0.00337	0.33018	0.00111	345.58	345.5
98	250	200	0.00069	1.45035	0.12581	0.02516	0.00229	0.30686	0.0007	345.356	345.24
99	300	200	0.00044	1.32032	0.10505	0.02101	0.00176	0.25018	0.00044	345.32333	345.24
100	50	200	0.00515	2.00649	0.23122	0.04624	0.0055	0.99131	0.00545	344.83	342.67

8 CONCLUSION

The present thesis work acomplish the objective of developing an efficient algorithm for the optimal design of a gravity sewer system.

- In this thesis, the ant colony optimization(ACO) metaheuristic is used to find optimal solution for the diameters and slopes of the pipe for the conjunctive least-cost design and operation of a sewerage system network. Total possible diameter and slope permutation were 90^{100}(approx. 2.656 X 10^{195}) and it is tough to find out the optimal pipe diameter and slopes from such a huge combinations if not using optimization technique (ACO). Hence, ACO is very promising as it can save a lot of time
- At the starting of the running of suggested program initial number of 1000 ants (1000 combinations) is used for the each iteration. The total 10 iteration are done for the problem. The total cost of the best solution obtained from the eighth iteration (out of 10niteration) was considered to be the Optimal.
- It is hoped that the program shall find direct application in field problems of design of the gravity sewer system. the developed program for sewer system analysis uses the commercially available diameter and slopes which is subsituted in the program . it is designedso that it can deal with discrete parameters of sewer system also.
- The total cost of initial model was Rs.**1,14,95,767** .and after 10 iteration by 1000 ants the cost is reduced up to Rs.**73,67,083.**

REFERENCES

Abbaspour, K.C., Schulin, R. and Van Genuchten, M.T., 2001. Estimating unsaturated soil hydraulic parameters using ant colony optimization.*Advances in water resources*, *24*(8), pp.827-841.

Afshar, M.H., 2005. A new transition rule for ant colony optimization algorithms: application to pipe network optimization problems. *Engineering Optimization*, *37*(5), pp.525-540.

Afshar, M.H., 2010. A parameter free Continuous Ant Colony Optimization Algorithm for the optimal design of storm sewer networks: Constrained and unconstrained approach. *Advances in Engineering Software*, *41*(2), pp.188-195.

Afshar, M.H., 2011. Colony-mutated ant system for pipe network optimization. *Iranian Journal of Science and Technology. Transactions of Civil Engineering*, *35*(C2), p.217.

Akin, E., 2003. *Object-oriented programming via Fortran 90/95* (Vol. 1). Cambridge University Press.

Argaman, Y., SHAMIR, U. and SPIVAK, E., 1973. Design of Optimal Sewerage Systems. *JOURNAL OF THE ENVIRONMENTAL ENGINEERING DIVISION-ASCE*, *101*(NEE 2), pp.266-266.

Bakalian, A., Wright, A., Otis, R. and deAzevedo-Netto, J., 1994. *Simplified sewerage: design guidelines*. UNDP-World Bank Water and Sanitation Program.

Benson Jr, R.E., 1985. The self-cleansing slope for partially full sewers. *Journal of Environmental Engineering*, *111*(6), pp.925-928.

Brown, K.G. and Koussis, A.D., 1987. LOTUS spreadsheet design for storm drain networks. *Journal of computing in civil engineering*, *1*(3), pp.197-213.

Cembrowicz, R.G. and Krauter, G.E., 1987. Design of cost optimal sewer networks. In *Proc. 4th Int. Conf. on Urban Storm Drainage, Lausanne, Switzerland* (pp. 367-372).

Chen, W.N., Zhang, J., Chung, H.S., Zhong, W.L., Wu, W.G. and Shi, Y.H., 2010. A novel set-based particle swarm optimization method for discrete optimization problems. *Evolutionary Computation, IEEE Transactions on*,*14*(2), pp.278-300.

Dajani, J.S. and Hasit, Y., 1974. Capital cost minimization of drainage networks. *Journal of the Environmental Engineering Division*, *100*(2), pp.325-337.

DEININGER, R.A., 1966. Computer aided design of waste collection and treatment systems.

Dorigo, M., Birattari, M. and Stützle, T., 2006. Ant colony optimization.*Computational Intelligence Magazine, IEEE*, *1*(4), pp.28-39.

Dorigo M, D. C. (1999). *The ant colony optimization meta heuristic. In: Come D,Dorigo M, Glover F, editors. New ideas in optimization.* London:: McGraw-HiII.

Dorigo, M., Di Caro, G. and Gambardella, L.M., 1999. Ant algorithms for discrete optimization. *Artificial life*, *5*(2), pp.137-172.

Elimam, A.A., Charalambous, C. and Ghobrial, F.H., 1989. Optimum design of large sewer networks. *Journal of Environmental Engineering*, *115*(6), pp.1171-1190.

Etter, D.M., 1986. *Structured FORTRAN 77 for engineers and scientists*. Benjamin-Cummings Publishing Co., Inc..

Gidley, J.S., 1986. Optimal design of sanitary sewers. In *Computing in Civil Engineering (1986)* (pp. 162-177). ASCE.

Gupta, A., Mehndiratta, S.L. and Khanna, P., 1983. Gravity wastewater collection systems optimization. *Journal of environmental engineering*,*109*(5), pp.1195-1209.

Gardner, C.B. and Carey, A.E., 2004. Trace metal and major ion input into the Olentangy River from an urban storm sewer. *Environmental science & technology*, *38*(20), pp.5319-5326.

Gatlin, L.L., 1963. Triplet frequencies in DNA and the genetic program.*Journal of theoretical biology*, *5*(3), pp.360-371.

Guo, Y., Walters, G. and Savic, D., 2008, September. Optimal design of storm sewer networks: Past, present and future. In *proceeding of 11th International Conference on Urban Drainage* (pp. 1-10).

Heaney, J.P., Wright, L.T., Sample, D., Field, R. and Fan, C.Y., 1999, August. Innovative methods for the optimization of gravity storm sewer design. In *Proc. the Eighth International Conference on Urban Storm Drainage*..

Holland, M.E., 1966. Computer models of waste-water collection systems.*PH D THESIS, ENG, HARVARD UNIV, MAY 1966. 95 P, 17 FIG, 7 TAB, 13 REF, 3 APPEND.*

Haghighi, A. and Bakhshipour, A.E., 2012. Optimization of sewer networks using an adaptive genetic algorithm. *Water resources management*, *26*(12), pp.3441-3456.

Jain, S.C., 1987. Free-surface swirling flows in vertical dropshaft. *Journal of Hydraulic Engineering*, *113*(10), pp.1277-1289.

Krink, T. and Løvbjerg, M., 2002. The lifecycle model: combining particle swarm optimisation, genetic algorithms and hillclimbers. In *Parallel Problem Solving from Nature—PPSN VII* (pp. 621-630). Springer Berlin Heidelberg.

Kennedy, J., 2011. Particle swarm optimization. In *Encyclopedia of machine learning* (pp. 760-766). Springer US.

Kulkarni, V.S. and Khanna, P., 1985. Pumped wastewater collection systems optimization. *Journal of environmental engineering*, *111*(5), pp.589-601.

Li, G. and Matthew, R.G., 1990. New approach for optimization of urban drainage systems. *Journal of Environmental Engineering*, *116*(5), pp.927-944.

Lemieux, P.F., Zech, Y. and Delarue, R., 1976. Design of a stormwater sewer by nonlinear programming-1. *Canadian Journal of Civil Engineering*, *3*(1), pp.83-89.

Moeini, R. and Afshar, M.H., 2013. Sewer network design optimization problem using ant colony optimization algorithm and tree growing algorithm. In *EVOLVE-A Bridge between Probability, Set Oriented Numerics, and Evolutionary Computation IV* (pp. 91-105). Springer International Publishing.

Mara, D. and Alabaster, G., 2008. A new paradigm for low-cost urban water supplies and sanitation in developing countries. *Water Policy*, *10*(2), pp.119-129.

Metcalf, E. and Eddy, E., 2003. Wastewater engineering: treatment and reuse. McGrawHill. *Inc., New York*.

MEASURE, P., 1996. PACKING PROBLEM.

Miles, S.W. and Heaney, J.P., 1988. Better than “Optimal” Method for Designing Drainage Systems. *Journal of Water Resources Planning and Management*, *114*(5), pp.477-499.

Mara, D.D. and Broome, J., 2008. Sewerage: a return to basics to benefit the poor. *Municipal Engineer*, *161*(4), pp.231-237.

Merritt, L.B. and Bogan, R.H., 1973. Computer-based optimal design of sewer systems. *Journal of the Environmental Engineering Division*, *99*(1), pp.35-53.

Manual on sewerage and sewage treatment'. new delhi: published by central public health and environmental Eng. Organization, Ministry of Urban Dev,. (1993).

Mays, L.W. and Wenzel, H.G., 1976. Optimal design of multilevel branching sewer systems. *Water Resources Research*, *12*(5), pp.913-917.

Mays, L.W. and Yen, B.C., 1975. Optimal cost design of branched sewer systems. *Water Resources Research*, *11*(1), pp.37-47.

Nyhoff, L.R. and Leestma, S.C., 1997. Fortran 90 for Engineers and Scientists, 1070 pages.

Navin, P.K. and Mathur, Y.P., 2016. Design Optimization of Sewer System Using Particle Swarm Optimization. In *Proceedings of Fifth International Conference on Soft Computing for Problem Solving* (pp. 173-182). Springer Singapore.

Rashid, M.M. and Hayes, D.F., 2010. Dynamic programming methodology for prioritizing sewerage projects. *Journal of Water Resources Planning and Management*, *137*(2), pp.193-204.

Robinson, D.K. and Labadie, J.W., 1981. Optimal design of urban storm water drainage systems.

Roy, R. D. (2012). A Novel Particle Swarm Optimization Algorithm for Multi-Objective Combinatorial Optimization Problem. 'International Journal of Applied Metaheuristic Computing (IJAMC)', 2(4), 41-57.

Sonnad, J.R. and Goudar, C.T., 2006. Turbulent flow friction factor calculation using a mathematically exact alternative to the Colebrook–White equation. *Journal of Hydraulic Engineering*, *132*(8), pp.863-867.

Swarna, V. and Modak, P.M., 1990. Graphs for hydraulic design of sanitary sewers. *Journal of Environmental Engineering*, *116*(3), pp.561-574.

Saatci, A., 1990. Velocity and depth of flow calculations in partially filled pipes. *Journal of environmental engineering*, *116*(6), pp.1202-1208.

Sleighthome, J., & Chivers, I. D. (1990). *Interactive Fortran 77: A Hands-On Approach. Computers and their applications (2nd ed.).* Chichester: E. Horwood.

Swamee, P.K., 2001. Design of sewer line. *Journal of Environmental Engineering*, *127*(9), pp.776-781.

Vítkovský, J.P., Simpson, A.R. and Lambert, M.F., 2000. Leak detection and calibration using transients and genetic algorithms. *Journal of Water Resources Planning and Management*, *126*(4), pp.262-265.

Walters, G.A. and Templeman, A.B., 1979. Non-optimal dynamic programming algorithms in the design of minimum cost drainage systems.*Engineering Optimization*, *4*(3), pp.139-148.

Weng, H.T. and Liaw, S.L., 2005. Establishing an optimization model for sewer system layout with applied genetic algorithm. *Journal of Environmental Informatics*, *5*(1), pp.26-35.

Weng, H.T. and Liaw, S.L., 2007. An optimization model for urban sewer system hydraulic design. *Journal of the Chinese Institute of Engineers*,*30*(1), pp.31-42.

Wu, Z.Y. and Simpson, A.R., 2002. A self-adaptive boundary search genetic algorithm and its application to water distribution systems. *Journal of Hydraulic Research*, *40*(2), pp.191-203.

Walters, G.A. and Smith, D.K., 1995. Evolutionary design algorithm for optimal layout of tree networks. *Engineering Optimization*, *24*(4), pp.261-281.

Walters, G.A. and Lohbeck, T., 1993. Optimal layout of tree networks using genetic algorithms. *Engineering Optimization*, *22*(1), pp.27-48.

Yen, B.C., Cheng, S.T., Jun, B.H., Voohees, M.L. and Wenzel, H.G., 1984. Illinois least cost sewer system design model. *User's guide, Department of Civil Engineering, University of Texas at Austin*.

Zhang, H. (2012). Ant Colony Optimization for Multimode Resource-Constrained Project Scheduling . *Journal of Management in Engineering*, Vol. 27, No. 2,150-159,.

Zhang, J., Cao, X.S. and Meng, X.Z., 2007. Sustainable urban sewerage system and its application in China. *Resources, Conservation and Recycling*, *51*(2), pp.284-293.

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