BEES ALGORITHM BASED OPTIMUM DESIGN of OPEN CANAL SECTIONS

I.Aydogdu*, A.Akın†

*Akdeniz University, Department of Civil Engineering,07058 Antalya, Turkey
† Department of Civil Engineering, YuzuncuYil University,65080 Van, Turkey

Accepted Date: 18 November 2011

Abstract

Engineering optimization has been used in a wide spread of fields that attracts the attention of designers. One of the engineering optimization problems is the optimization of the open canals which are mostly used as water transfer structures in water resources. Design of open canal structures is a complex task due to the fact that the designer has to select suitable dimensions of sections within certain range of values and such selection should satisfy the flow requirements to convey a specific discharge in the canal. In this study, dimensions of cross sections of open canals are optimized by using bees algorithm in order to investigate performance of this algorithm in the optimum design of open canal problems. Four design problems are considered to optimize and results obtained from these problems are compared to results obtained from previous studies.

Keywords: Open Canal;bees algorithm; optimization.

1. Introduction

Several studies about the optimum design of open canals have been presented, and in these studies, open canals have been optimizedusing different conditions. In majority of these studies, optimum designproblem of open canals is analyzed for different open canal geometries under uniform flow conditionsor[1-5]. However, there are considerably fewer research studies thathave considered thisoptimum design problem under non-uniform flow conditions or [6, 7].

Many optimization methods have been used in the optimum design of open canals. Generally, nonlinear programming techniques such as Lagrange Multipliers have been usedas a classical optimization methodin order to solve optimization of open canal problems. In recent years, meta-heuristic optimization techniques have been developed and applied to engineering optimization problems. Meta-heuristic search techniques are generally inspired from the nature and explore the design spacein order to determine the optimal or near optimal solutions by following some rulesaccording tothe mechanism ofmeta-heuristic algorithms used. Genetic algorithm, evolutionary strategies, simulating annealing, tabu search, ant colony optimization, particle swarm optimization, differential evolution, firefly algorithm and bees algorithm are some of the meta-heuristic techniquesused in engineering optimization algorithms. Bees algorithm is one of the newest meta-heuristic search techniques developed by Pham et al. in 2005 [8]. This optimization technique is applied to many engineering fields such as training neural networks for pattern recognition, analysis of computer vision and image, finding multiple feasible solutions to preliminary design problems, data clustering, scheduling jobs for a production machine, tuning a fuzzy logic controller for a robot gymnast, optimizing the design of mechanical components, multi-objective optimization problems and optimum design of continuous engineering problems [9-12].

2. General Mathematical Modeling of the Optimization Problem

In this study, an optimization algorithm is developed in order to reach objectiveof the optimization problem while satisfying certain limitations in the problems. Objective of this optimization problem is minimizing the cost of open canal. Therefore objective function in theoptimum design problemof opencanals is defined as minimizing the cost of open canal, *C*, as shown in the following formula,

$$\text{Minimize } C = \beta_L P + \beta_E A + \beta_A \int_0^A a\, d\eta \tag{1}$$

where β_L is unit lining cost (TL/L^2) , β_E is the unit excavation cost (TL/L^3), β_A additional cost of excavation per unit depth in (TL/L^4), a is the flow at height η, P is the wetted perimeter, A is the flow area of the open canal, L is the length of the open canal andTL is the acronym of Turkish Liras.

This objective function is subject to flow requirements. Uniform flow condition in this optimization problem is represented as Manning's uniform flow equation given in the following formula;

$$Q = \frac{1}{n} A R^{2/3} S^{1/2} \tag{2}$$

where, n is manning roughness coefficient, R is hydraulic radius, and S bottom slope of the open canal. Equations (1) and (2) can be represented as dimensionless parameters used in the literature [5]. These dimensionless parameters are defined by using length scale represented as follows.

$$\lambda = \left(\frac{Qn}{S^{1/2}} \right)^{3/8} \tag{3}$$

Dividing both sides $B_E \lambda^2$ in equation (1) and λ^2 in equation (2), objective and constraint functions can be rewritten as follows:

$$C^* = \beta_L{}^* P^* + \beta_E{}^* A^* + \frac{\beta_A{}^* \int_0^A a\, d\eta}{\lambda^3} \tag{4}$$

$$1 - \left(A^*\right)^{5/3} \left(P^*\right)^{-2/3} = 0 \tag{5}$$

There are four different canal shapes will be solved with that circular triangular, rectangular and trapezoidal cross sections shown in Figures 1, 2, 3 and 4. Objective function and constraint function are rearranged for each canal shape shown in following equations.

For triangular cross section:

$$C^*(y_n, m) = 2\beta_L{}^* y_n \sqrt{1+m^2} + m\, y_n{}^2 + \frac{\beta_A{}^* y_n{}^3}{3} \tag{6}$$

$$g(y_n, m) = 1 - \frac{\left(m y_{n*}^2\right)^{5/3}}{\left(2\, y_n \sqrt{1+m^2}\right)^{2/3}} = 0 \tag{7}$$

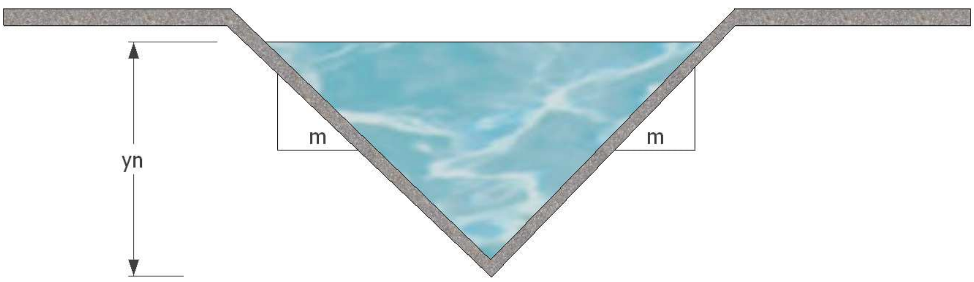


Fig. 1. Geometric dimensions of open canal with triangular cross sections

For rectangular cross section:

$$C^*(y_n, b) = \beta_L^*(2y_n + b) + b\,y_n + \frac{\beta_A^* b\,y_n^2}{2} \tag{8}$$

$$g(y_n, b) = 1 - (b\,y_n)^{5/3}(2y_n + b)^{-2/3} = 0 \tag{9}$$

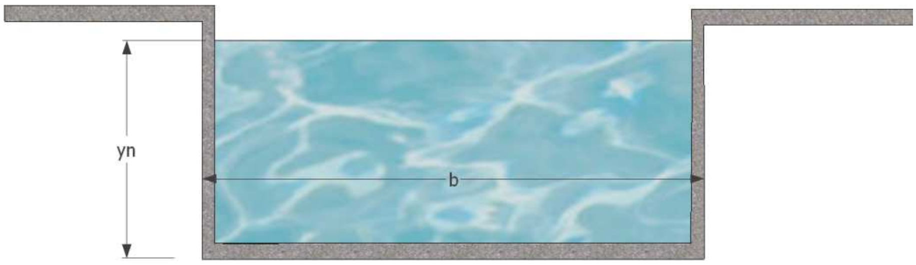


Fig. 2. Geometric dimensions of open canal with rectangular cross sections

For trapezoidal cross section:

$$C^*(y_n, m, b) = \beta_L^*\left(2y_n\sqrt{1+m^2} + b\right) + \left(b\,y_n + m\,y_n^2\right) + \beta_A^*\left(\frac{b\,y_n^2}{2} + \frac{m\,y_n^3}{3}\right) \tag{10}$$

$$g(y_n, m, b) = 1 - \left(b\,y_n + m\,y_n^2\right)^{5/3}\left(2y_n\sqrt{1+m^2} + b\right)^{-2/3} = 0 \tag{11}$$

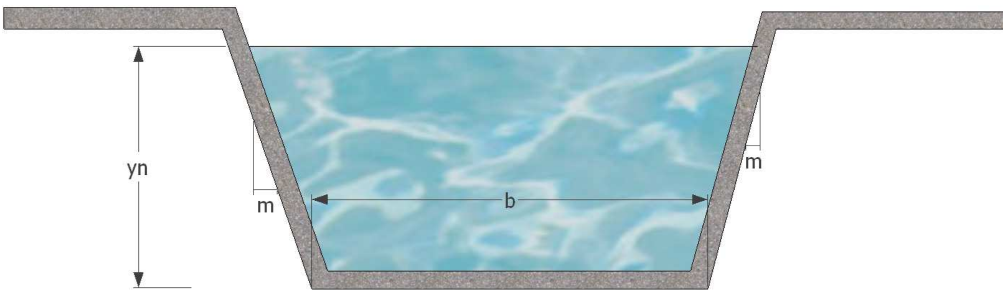


Fig. 3. Geometric dimensions of open canal with trapezoidal cross sections

For circular cross section:

$$C^*(y_n, r) = \beta_L{}^*\left(r\left(\pi - 2\arcsin\left(\frac{r-y_n}{r}\right)\right)\right) +$$
$$\frac{r^2}{2}\left(\pi - 2\arcsin\left(\frac{r-y_n}{r}\right) - 2\left(\frac{r-y_n}{r}\right)\frac{\sqrt{r^2-(r-y_n)^2}}{r}\right) + \beta_A^*\left(\frac{r^2}{2}\right) \tag{12}$$
$$\left(-(r-y_n)\left(\pi - 2\arcsin\left(\frac{r-y_n}{r}\right)\right) + 2\sqrt{r^2-(r-y_n)^2}\left(\frac{2r^2+(r-y_n)^2}{3r^2}\right)\right)$$

$$g(y_n, r) = 1 - \frac{\left(\frac{r^2}{2}\left(\pi - 2\arcsin\left(\frac{r-y_n}{r}\right) - 2\left(\frac{r-y_n}{r}\right)\frac{\sqrt{r^2-(r-y_n)^2}}{r}\right)\right)^{5/3}}{\left(r\left(\pi - 2\arcsin\left(\frac{r-y_n}{r}\right)\right)\right)^{2/3}} = 0 \tag{13}$$

where, y_n is flow depth, b is bottom depth, m is side slope and r is radius of the open canal which are shown in Figures 1, 2, 3 and 4.

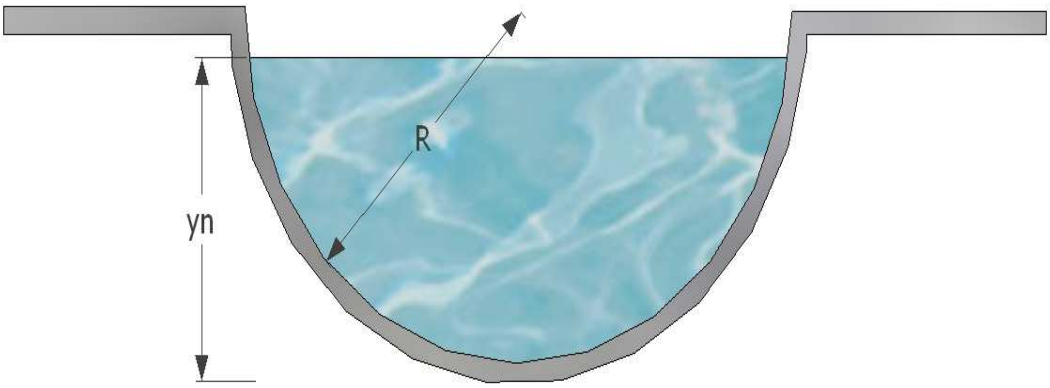


Fig. 4. Geometric dimensions of open canal with circular cross sections

3. Bees Algorithm

The Bees Algorithm is biologically inspired by the natural behavior of bees. This technique is adopted from the food foraging behavior of a colony of honey bees when they collect nectar or pollen in order to make less effort. Swarm bees can spread out to huge fields in order to find much more food sources at the same time. A colony feeds by spreading its foragers to good fields. Practically, a large number of bees visit and collect nectar or pollen from flower patches with plentiful amounts of food, instead of visiting flower patches with less nectar or pollen [7-9]. This behavior provides feeding of the colony with less effort. Bees algorithm is mentioned in the following steps.

Step 1: In step1, values of parameters are defined in order to set in to the Bees algorithm. These parameters are number of scout bees (NSB), number of elite bees (NEB), number of recruit bees around elite bees (RBEEB), number of best selected patch (NBSP), number of recruit bees around best selected (RBEBS), number of cycles and patch radius. At first, NSB candidate design is generated as randomly which satisfy design limitations. Then candidate design is evaluated, sorted in ascending order of value of the objective function and stored in a memory.

Step 2: In second step, first NEB designs are assigned to the elite bees in the memory. RBEEB designs ($\upsilon_{i,j}$) are generated in the neighborhood of elite bees($x_{i,j}$) for each elite bee by using the formula $\upsilon_{i,j} = x_{i,j} + \Phi_{ij}(x_{i,j} - x_{k,j})$ (k is a solution in the neighborhood of elite bee i, Φ is a random number in the range [-1,1]). As a result RBEEB×NEB designs are generated. These designs are evaluated according to the objective function value and checked whether design limitation is satisfied or not. If the best feasible design vector is better than the design vector of the i^{th} elite bee, the new design vector is assigned as the new design vector of the i^{th} elite bee.

Step 3: Next NBSP designs are assigned to the best selected patches. Similar to step 2, RBEBS designs are generated in the neighborhood of the best selected patch. Then, these designs are evaluated according to the objective function value and checked whether the design limitation is satisfied or not. If the best feasible design vector is better than the design vector of the best selected patch, the new design vector is assigned as the new design vector of the best selected patch.

Step 4: Remaining bees in the patch search randomly and generate new designs among elite bees and best selected patches. Fitness of these designs are calculated. If the new design vector is better than any design vector in the patch, new design vector is replaced with the worst design vector in the patch.

Step 2 and step 4 continues by the time the maximum iteration is reached.

4. Numerical Applications

Optimum design problem of open canals having four different shapes are solved by using Bees Algorithm. Objective functions and constraint functions of these numerical applications were given in equations (6), (7), (8), (9), (10), (11), (12) and (13). There are many tests that have been performed in order to adjust Bees Algorithm search parameters. After these tests, following search parameters are defined in this study: Number of scout bees (NSB) = 50, number of elite bees (NEB) = 20, number of recruit bees around elite bees (RBEEB) = 10, number of best selected patch (NBSP) =10, number of recruit bees around best selected (RBEBS) =5, number of cycles=10, patch radius =10.

There are two exercises done in this study. In the first exercise, excavation cost is not taken into account which means that $\beta_A = 0$. In the first exercise, optimization problems are solved for all type of canal shapes by using Bees Algorithm (BA) and obtained results are compared with previous studies. All obtained results for exercise are tabulated in Table 1.

Table 1. Optimum design of open canal by using lagrange multiplier (LM), differential evolution (DE)and bees algorithms(BA)

		Design Variables				Cost
		y_n	***m***	***b***	***r***	
LM	Triangular Section	1.297	1	-	-	5.3507
DEA		1.297	1	-	-	5.3507
BA		**1.299**	**0.996**	**-**	**-**	**5.3474**
LM	Rectangular Section	0.917	-	1.834	-	5.3498
DEA		0.91721	-	1.83358	-	5.3498
BA		**0.939**	**-**	**0.179**	**-**	**5.3488**
LM	Trapezoidal Section	0.968	0.577	1.117	-	4.976
DEA		0.968	0.577	1.118	-	4.9741
BA		**0.969**	**0.579**	**1.112**	**-**	**4.9726**
LM	Circular Section	1.004	-	-	1.004	4.7376
DEA		1.004	-	-	1.00387	4.737
BA		**1.01**	**-**	**-**	**1**	**4.735**

Effectiveness of β_A and β_L parameters are investigated in the second exercise. In previous studies, β_A and β_L parameters are investigated for only open canalhaving triangular shapeby using Differential Evolution algorithm and Numerical Optimization techniques [5, 13]. Therefore in these parameters investigated for open canal having triangular shape.Obtained results are compared with previous studies shown in Figures 5 and 6.

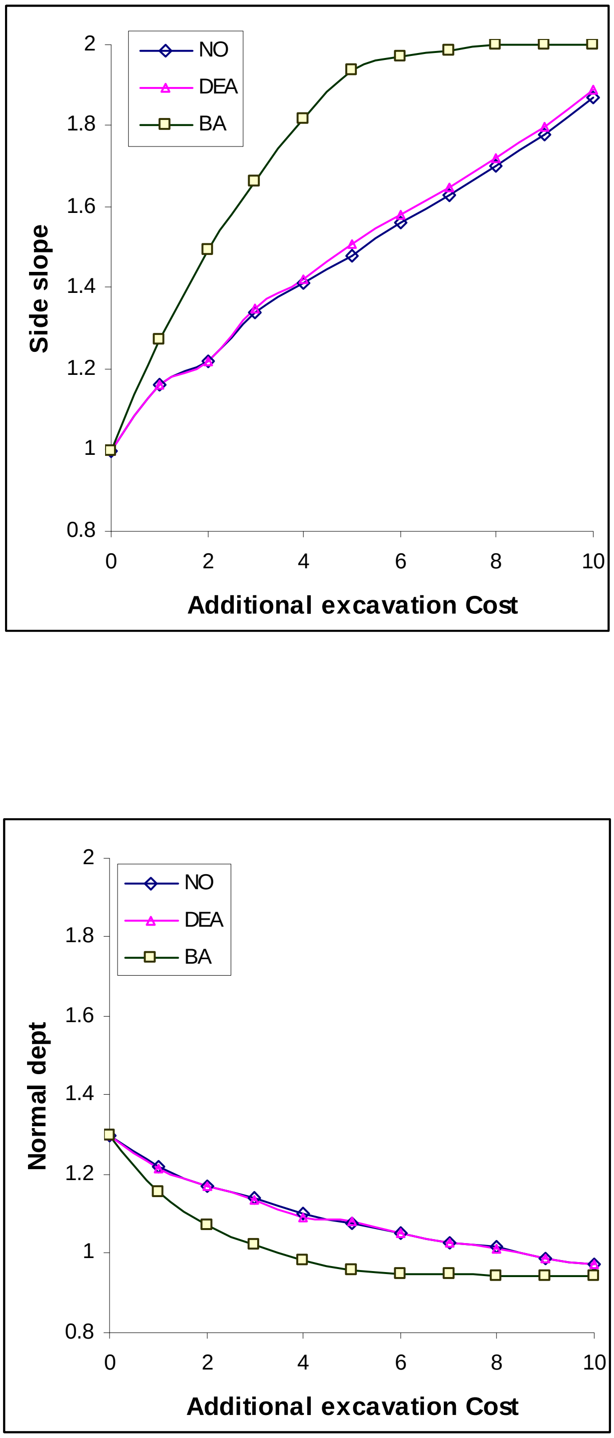
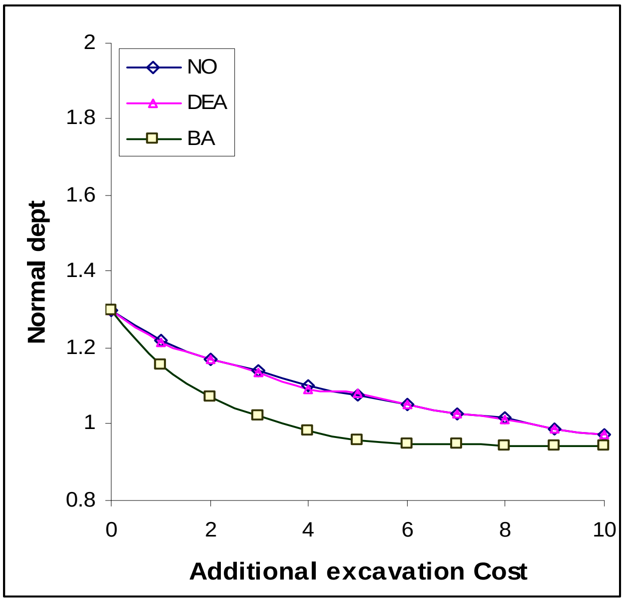


Fig. 5.Variation of optimum nondimensional side slope and normal depth of a triangular section with $\beta_L = 1.0$



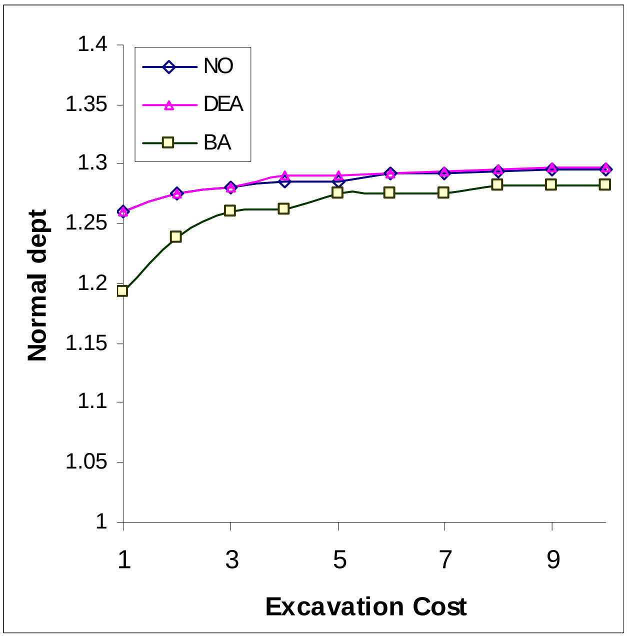


Fig. 6.Variation of optimum nondimensional side slope and normal depth of a triangular section with $\beta_A = 0.5$

5. Conclusions

In this study, Bees algorithm is applied to the optimum design of open canal problems. There are four examples solved with different canal shapes (circular triangular, rectangular and trapezoidal). Results obtained from these examples are compared to previous studies shown in the Table 1 and Figures 5 and 6. It is clearly seen from Table 1 that better solutions are obtained for all different canal sections when Bees Algorithm is used. It is concluded from these comparisons that Bees algorithm is reliable, robust and effective algorithm in the optimization of open canal problems which is one of the engineering design optimization problems. In addition, Figures 5 and 6 show that adjustment of unit cost parameters (β_A and β_L) are effective parameters on the optimum cross sections of the open canals.

Variation of these parameters make a considerably changes on the design variables optimum design of the open canal. Many tests have performed in order to adjust Bees Algorithm parameters for optimum design of open canal problems. As a result of these tests, best solutions are obtained for all canal shapes within following search parameters: Number of scout bees (NSB) = 50, number of elite bees (NEB) = 20, number of recruit bees around elite bees (RBEEB) = 10, number of best selected patch (NBSP) =10, number of recruit bees around best selected (RBEBS) =5, number of cycles=10, patch radius =10.It is also concluded from these tests that adjustment of bees algorithm parameters is important to attain the convergence. The method may not converge at all or converges to a local optimum if unsuitable values are assigned to these parameters. Therefore, this study is a good means to adjust parameters for engineering optimization problems.

References

[1] Babaeyan-Koopaei, K., Valentine, E. M., and Swailes, D. C. Optimal design of parabolic-bottomed triangle canals. *Journal of Irrigation and Drainage Engineering.* 126(6), 408–411, 2000.

[2] Babaeyan-Koopaei, K., Dimensionless curves for normal depth calculations in canal sections. *Journal of Irrigation and Drainage Engineering.* 127(6), 386–389, 2001.

[3] Chahar, B.R.. Optimal Design of a special Class of Curvilinear Bottomed Channel Section. *Journal Hydraulic Engineering, ASCE*. 133(5), 571-576, 2007.

[4] Turan, M.E., and Yurdusev, M.A., Optimization of Open Canal Cross Sections by Differential Evolution Algorithm *Mathematical and Computational Applications*. 16(1), 77-86, 2011

[5] Swamee, P.K., Optimal irrigation canal sections. *Journal of Irrigation and Drainage Engineering*. 121, 467–469, 1995.

[6] Pham, D.T., Afify, A.A., Koc, E., Manufacturing cell formation using the Bees Algorithm. IPROMS 2007 *Innovative Production Machines and Systems Virtual Conference*, Cardiff, UK 2007.

[7] Pham, D.T., Ghanbarzadeh A., Koc E., Otri S., Rahim S. and Zaidi M. The Bees Algorithm. *Technical Note, Manufacturing Engineering Centre,* Cardiff University, UK 2005.

[8] Pham, D.T., Koç, E., Lee, J.Y., and Phrueksanant, J. Using the Bees Algorithm to schedule jobs for a machine, *Proc Eighth International Conference on Laser Metrology, CMM and Machine Tool Performance,* LAMDAMAP, Euspen, UK, Cardiff, 430–439, 2007.

[9] Yang X.S., Engineering Optimizations Via Nature-Inspired Virtual Bee Algorithms. *Artificial Intelligence and Knowledge Engineering Applications: A Bioinspired Approach*, Lecture Notes In Computer Scıence 3562, 317-323, Springer Berlin / Heidelberg, 2005.

[10] Pham D.T., Castellani, M. and Ghanbarzadeh, A. Preliminary design using the Bees Algorithm, *Proc Eighth International Conference on Laser Metrology, CMM and Machine Tool Performance*, LAMDAMAP, Euspen, UK, Cardiff, 420–429, 2007.
[11] Pham D.T., Darwish, A.H., Eldukhri, E.E., and Otri, S. Using the Bees Algorithm to tune a fuzzy logic controller for a robot gymnast.,*Proceedings of IPROMS Conference*,Whittles, Dunbeath, Scotland, 546-551, 2007.
[12] Aksoy, B., and Altan-Sakarya, A. B. Optimal lined channel design. *Canadian. J. Civ. Eng*., 33(5), 535–545, 2006.