Optimum Design of Cellular Beams Via Bat Algorithm With Levy Flights

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Abstract

Recently, several non-deterministic search techniques have been proposed for the development of structural optimization problems. This study presents a bat algorithm for the optimum solution of engineering optimization problems. Bat algorithm is based on the micro-bats' echolocation capability. They use echo sounder to identify prey, keep away from obstacles (barriers) and settle their roosting crevices in the darkness. Bats give out a very powerful sound and then listen its echo from the nearby items. They even use the time retard from the emission and sensing of the echo. They can notice the distance and position of the target, target's characteristics and even the target's moving speed such as very small insects. Bat algorithm is an optimum design algorithm for the automatization of optimum design process, during which the design variables are chosen for the minimum objective function value limited by the design constraints. Three varied cellular beam problems subjected different loading are selected as numerical design examples. Also in this study, Levy Flights is adapted to the simple bat algorithm for better solution. For comparison, three cellular beam problems solved for the optimum solution by using bat algorithm and bat algorithm with Levy Flights technique. Results bring out that bat algorithm is effective in finding the optimum solution for each design problem. Moreover, adaptation of Levy Flights technique to simple bat algorithm generates better solutions than the solutions obtained by simple bat algorithm.

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1 Introduction

In recent years, as an alternative to mathematical programming based techniques, several meta-heuristic or evolutionary algorithms have been improved. Main aim of researchers developing these methods is to deal with shortcomings of traditional mathematical programming techniques in solving optimization problems. The gradient of objective function is calculated by applying automatic differentiation formulas [Evtushenko, 1998]. However these meta-heuristic algorithms don't need the convexity of the objective function and constraint functions or the gradient information. So, to determine the best solution of discrete engineering optimization problems more actively than with those based on mathematical programming techniques became feasible. Metaheuristic techniques are widely applied in optimum design of steel structures [Hasancebi, 2007], [Hasancebi, 2008] [Saka, 2009].After the successful applications of early meta-heuristic techniques in structural optimization, number of new meta-heuristic algorithms have been emerged which are even more efficient and powerful than the earlier methods. One of the recent supplementation to these novel optimization algorithms is the bat algorithm. In the present study, bat algorithm and bat algorithm with Levy Flights technique are applied for the automation of optimum design algorithm of cellular beams. Bat algorithm is depended on the echolocation behavior of bats with changeable pulse rates of emission and loudness [Yang, 2009].Bats use sonar called echolocation, to detect prey, settle down their roosting crevices in darkness and avoid obstacles. All bats use echolocation to discover prey, to perceive distance and by the echolocation they also know the distinctness between background obstacles and prey [Saka et al., 2013].

Cellular beams are steel profiles with circular openings. These circular openings are made by cutting a rolled beam web in a half circular pattern along beam's centerline and re-welding the rolled steel sections' two halves. And this circular opening which belongs to the original rolled beam while decreasing the overall weight of the beam, increases the whole beam depth, section modulus and moment of inertia.This consequently leads to deeper and stronger section. A cellular beam's geometrical parameters are illustrated in figure 1.

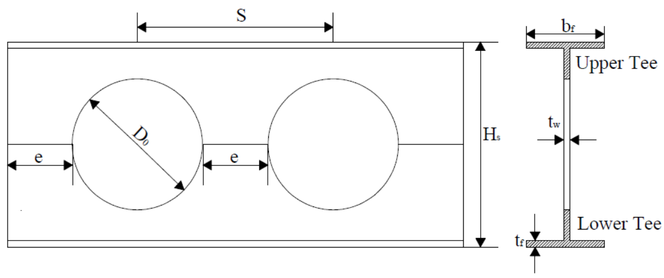

Figure 1: Cellular Beam's Geometrical Parameters

Optimum design algorithm selects steel UB sections, optimum number of holes and the optimum hole diameter for a cellular beam in such a way that all the design constraints are satisfied and the beam's weight is minimum. Design provisions are taken from the Steel Construction Institute Publication Number 100 and BS5950 [BS 5950, 2000].

2 Material and Methods

2.1 Optimum Design of Cellular Beams

The optimum design problem can be identified as follows;

Minimize

$$f(x), (x = x_1, x_2, ..., x_n) \tag{1}$$

Subjected to

$$gi(x) \leq 0, (i = 1, 2, ..., p) \tag{2}$$

$$hj(x) = 0, (j = 1, 2, ..., m) \tag{3}$$

where

$$L_{xk} \leq x \leq U_{xk}, k = 1, 2, ..., n \tag{4}$$

Here, $f(x)$ represents objective function, x denotes the decision solution vector, n is the total number of decision variables. L_{xk} and U_{xk}, are the lower and the upper bound of each decision variable, respectively. m represents equality constraints number and p denotes inequality constraints number [Seker & Dogan, 2012].

2.2 Bat Algorithm With Levy Flights

Bat algorithm is instigated by Yang [Yang, 2009]. The algorithm simulates echolocation capability of bats. The steps of the algorithm with Levy Flights are as follows:

1. Initialize the parameters: Initialize the bat population with position x_i and velocity v_i. Each bat represents a candidate solution x_i, (i=1,...,n) to the optimization problem with objective function f(x).Initialize the loudness A_i.and pulse rates r_i. Describe pulse frequency f_i. at x_i.

2. Calculate the new solutions: Calculate the new solutions x_i^t and velocities v_i^t at step time t as

$$x_i^t = x_i^{t-1} + v_i^t \tag{5}$$

$$v_i^t = v_i^{t-1} + (x_i^{t-1} - x^*)f_i \tag{6}$$

Where x* is the actual global best solution which is positioned after comparison whole solutions among all of the micro-bats.

3. If a randomly generated number $r < r_i$, decide a solution among the best solutions.

4. Generate a local solution: Create a local solution by a local random walk around the selected best solution.

$$x_{new} = x_{old} + rA^t \tag{7}$$

Where the random number r is drawn from (-1,1) while A^t is the average loudness of all micro-bats at this step time.

5. If a randomly generated number $r > A_i$ and $f(x_i) < f(x^*)$, increase r_i and reduce A_i and accept new solutions.

6. Rank the bats and obtain current best x^*.

7. Generate hunter's new positions using Levy flights: The algorithm creates a new solution.

$$x_{new} = x_i^t \pm \beta\lambda r(x_i^t - x_i^{t-1}) \tag{8}$$

Where, β is the step size which is chosen with regard to the design problem under consideration ($\beta > 1$) , r: random number from normal distribution and λ: length of step size which is decided according to random walk with Levy Flights.

8. Repeat steps 2 to 7 until max. number of iterations is satisfied [Saka et al., 2013].

3 Design Examples

3.1 Cellular Beam With 8-m Span

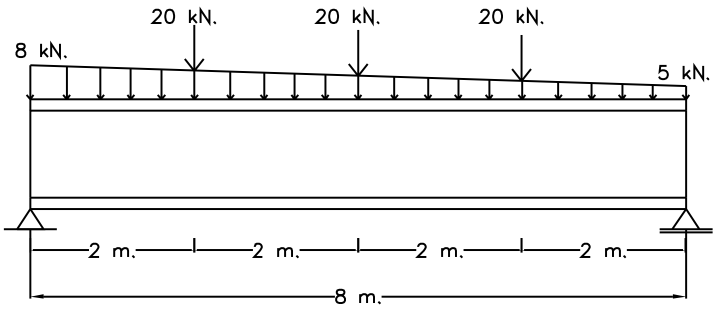

Figure 2: 8 m. Simply Supported Cellular Beam

The simply supported beam shown in figure 2 is selected as first design example. The beam has a span of 8 m and carries a trapezoidal distributed load. The beam is also carries three 20 kN concentrated loads as shown in

Table 1: Optimum designs of cellular beam obtained by two metaheuristic techniques

	BAT-L.F	BAT
Optimum Section	UB-305x102x25	UB-305x102x25
Hole Diameter (mm)	406	393
Total Number of Holes	18	18
Max. Strength Ratio	1	1
Min. Weight	162.99 kg.	167.05 kg.

the same figure. Grade 50 steel which has the design strength 355 MPa is adopted for the beam and the modulus of elasticity (E) is taken as 205 kN/mm2.

The 8 m cellular beam is separately designed by simple bat algorithm and bat algorithm with Levy Flights technique. The optimum designs of the problem obtained by metaheuristic methods are tabulated in table 1.

It is noticed that the optimum result is obtained by bat algorithm with Levy Flights technique with the weight of 162.99 kg. In this design bat algorithm with Levy Flights technique method selects 305x102x25 UB section for the cellular beam. Moreover, it decides that the cellular beam should have 18 circular holes each having 406 mm diameter. The design history curves for metaheuristic techniques are demonstrated in figure 3.

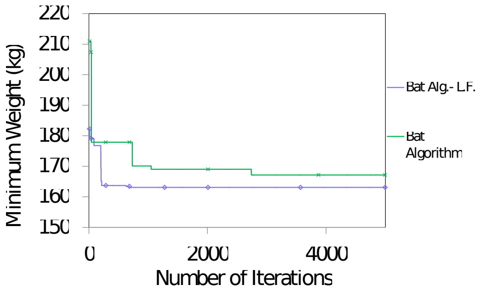

Figure 3: The design history graph for 8 m. cellular beam

3.2 Cellular Beam With 9-m Span

The simply supported cellular beam shown in figure 4 with a span of 9 m carries a trapezoidal distributed load. The beam is also subjected to a concentrated load of 60 kN at beam's mid-span as shown in the same figure. The max. displacement of the beam under these loads is restricted to 25 mm. And other design constraints are implemented from BS5950. Grade 50 steel which has the design strength 355 MPa is adopted for the beam and the modulus of elasticity (E) is taken as 205 kN/mm2.

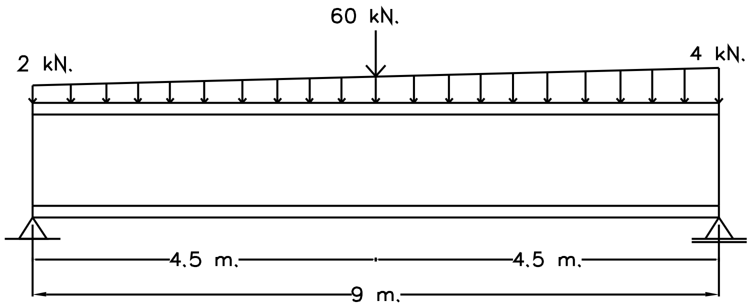

Figure 4: 9 m. Simply Supported Cellular Beam

The 9 m cellular beam is separately designed by simple bat algorithm and bat algorithm with Levy Flights technique. The optimum designs of the problem obtained by metaheuristic methods are tabulated in table 2.

Table 2: Optimum designs of cellular beam obtained by two metaheuristic techniques

	BAT-L.F	BAT
Optimum Section	UB-305x102x25	UB-305x102x25
Hole Diameter (mm)	395	389
Total Number of Holes	21	21
Max. Strength Ratio	1	1
Min. Weight	183.38 kg.	185.57 kg.

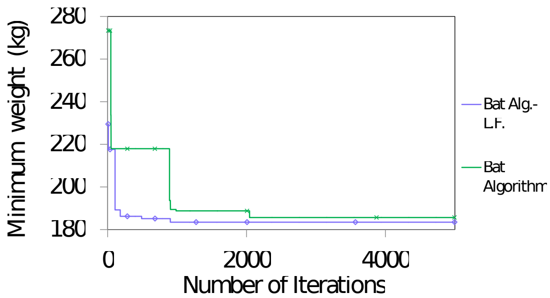

Figure 5: The design history graph for 9 m. cellular beam

It is noticed that the optimum result is obtained by bat algorithm with Levy Flights technique with the weight of 183.38 kg. In this design bat algorithm with Levy Flights technique method selects 305x102x25 UB section for the root beam. Moreover, it decides that the cellular beam should have 21 circular holes each having 395 mm diameter. The design history curves for metaheuristic techniques are demonstrated in figure 5 .

3.3 Cellular Beam With 10-m Span

The simply supported cellular beam shown in figure 6 with a span of 10 m carries a triangular distributed load. The beam is also subjected to two concentrated loads of 40 kN as shown in the same figure. The max. displacement of the beam under these loads is restricted to 28 mm. And other design constraints are implemented from BS5950. Grade 50 steel which has the design strength 355 MPa is adopted for the beam and the modulus of elasticity (E) is taken as 205 kN/mm2.

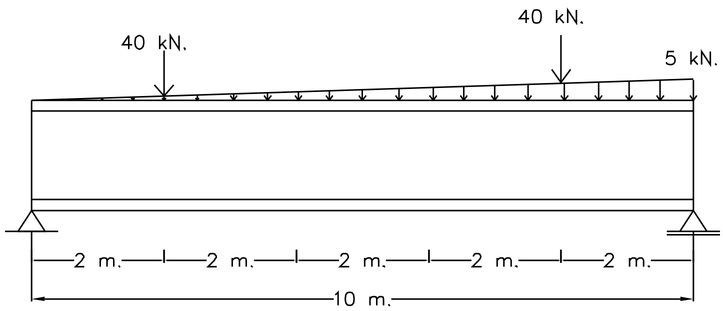

Figure 6: 10 m. Simply Supported Cellular Beam

The 10 m cellular beam is separately designed by simple bat algorithm and bat algorithm with Levy Flights technique. The optimum designs of the problem obtained by metaheuristic methods are tabulated in table 3.

It is noticed that the optimum result is obtained by bat algorithm with Levy Flights technique with the weight of 203.05 kg. In this design bat algorithm with Levy Flights technique method selects 305x102x25 UB section for the root beam. Moreover, it decides that the cellular beam should have 23 circular holes each having 401 mm diameter. The design history curves for metaheuristic techniques are demonstrated in figure 7.

Table 3: Optimum designs of cellular beam obtained by two metaheuristic techniques

	BAT-L.F	BAT
Optimum Section	UB-305x102x25	UB-305x102x25
Hole Diameter (mm)	401	377
Total Number of Holes	23	24
Max. Strength Ratio	1	1
Min. Weight	203.05 kg.	207.71 kg.

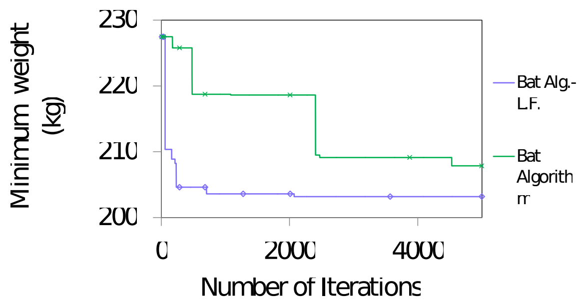

Figure 7: The design history graph for 10 m. cellular beam

4 Conclusions

In this study it is presented that the optimum design problem of cellular beams turns out to be discrete nonlinear programming problem when formulated according to the design restrictions specified in SCI publications number 100. This formulation is conducted such that the sequence number of Beam section, total number of holes and hole diameter in the beam are treated as design variables. Three design examples are selected to examine the performance of the bat algorithm. Results reveal that bat algorithm is an effective and robust method that can successfully be used in engineering optimization problems and finds good optimum solutions. Further, in order to increase the chance of bat algorithm, search procedure of the algorithm is modified by use of Levy flights. It is estimated that Levy flights increases the performance of the algorithm.

References

[Hasancebi, 2007] Hasancebi, O. (2007). Discrete approaches in evolution strategies based optimum design of steel frames. *Struct. Eng. Mech., 26(2)*, 191-210.

[Evtushenko, 1998] Evtushenko, Y.G., (1998). Computation of exact gradients in distributed dynamic systems. *Optimization methods and software. (9)*, 45-75.

[Hasancebi, 2008] Hasancebi, O. (2008). Adaptive evolution strategies in structural optimization: Enhancing their computational performance with applications to large-scale structures. *Computers and Structures. 86*, 119132.

[Saka, 2009] Saka, M.P., (2009). Optimum Design of Steel Sway Frames to BS5950 Using Harmony Search Algorithm. *Journal of Constructional Steel Research.65(1)*,36-43.

[Yang, 2009] Yang, X.S., (2009). Firefly Algorithms for Multimodal Optimization. Stochastic Algorithms: Foundations and Applications. *International Symposium on Stochastic Algorithms: Foundations and Applications. SAGA 2009.*, 169-178. Springer, Berlin, Heidelberg

[Saka et al., 2013] Saka, M.P., Dogan, E., Aydogdu, I., (2013). *Review and Analysis of Swarm-Intelligence Based Algorithms.* Swarm Intelligence and Bio-Inspired Computation, Theory and Applications, Chapter: 2, Publisher: Elsevier

[Seker & Dogan, 2012] Seker, S., Dogan, E., (2012). Performance Testing of Hunting Search Algorithm in Finding the Optimum Solution of Engineering Design Problems. *7th International Architecture and Engineering Symposiums*, Gemikonagi, TRNC

[BS 5950, 2000] British Standard Institution, (2000). *Structural Use of Steelworks in Building. Part 1. Code of Practice for Design in Simple and Continuous construction, hot rolled sections.*London: U.K.