Hunting Search Algorithm Based Design Optimization of Steel Cellular Beams

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ABSTRACT
The present study examines a hunting search based optimum design algorithm for cellular beams. Hunting search is a numerical optimization method inspired by group hunting of animals. The proposed algorithm selects the optimum UB section to be used in the production of a cellular beam subjected to a general loading, the optimum holes diameter and number of these holes in the beam. Furthermore, this selection is also carried out such that the design limitations are satisfied and the weight of the cellular beam is the minimum. A design example is considered to demonstrate the application of the optimum design algorithm developed.

Categories and Subject Descriptors
G.1.6 [**Numerical Analysis**]: Optimization – *Global optimization, constrained optimization, stochastic search programming*

Keywords
Optimum structural design, hunting search algorithm, minimum weight, metaheuristic techniques, steel cellular beams

1. INTRODUCTION
One of the recent additions to optimization algorithms is hunting search algorithm, which is inspired by group hunting of animals. Hunters involved in the group encircle and catch their prey abiding by the certain strategies. One prey is selected and the hunting group gradually moves toward it. The hunters avoid standing in the wind such that the prey senses their smell. In optimization process, each of the hunters indicates a solution for a particular problem. Similar to animals cooperate to find and catch the prey, the design process seeks to find the optimum solution.

2. DESIGN OF CELLULAR BEAMS
Design constraints include the displacement limitations, flexural and shear capacity, web post buckling, vierendeel bending of tees, local buckling and practical restrictions. The design procedure given here is taken from “Design of Composite and Non-composite Cellular Beams” [1]. The design methods are consistent with BS5950 part 1 and 3, [2]. The basic geometry and notations used for cellular beams are shown in Figure 1. Although the diameter of holes and spacing between their centres are left to designer to select the following ratios are required to be observed.

$$1.08 < S / D_0 < 1.5 \quad \textit{and} \quad 1.25 < H_S / D_0 < 1.75 \qquad (1)$$

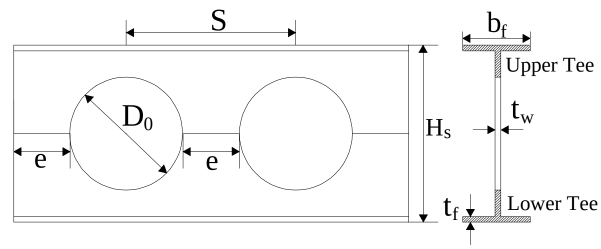

Figure 1. Geometry and notation for cellular beam

3. OPTIMUM DESIGN PROBLEM
The design of a cellular beam requires the selection of a rolled beam from which the cellular beam is to be produced, the selection of circular hole diameter and the selection of spacing between the centres of holes or number of holes in the beam. The design problem turns out to minimize the weight of the cellular beam. W is the weight of the cellular beam, D_0 is hole diameter, ρ is density of steel, A is total area of profile, NH is number of holes, H_S is overall depth of cellular beam, L is span of cellular beam and S is distance between centers of holes.

$$W = \rho \times A \times L - \left(\pi (D_0 / 2)^2 \times NH\right) \qquad (2)$$

4. HUNTING SEARCH ALGORITHM
Hunting search method based optimum design algorithm has six basic steps, which is outlined in the following [3].

Step 1 Initializing design algorithm and parameters: *HGS* defines the hunting group size which is the number of solution vectors in hunting group, *MML* represents the maximum movement toward the leader and *HGCR* is hunting group consideration rate which varies between 0 and 1.

Step 2 Generation of hunting group: On the basis of the number of hunters (*HGS*), hunting group is initialized by selecting randomly sequence number of steel sections (I_i) for each group.

$$\mathrm{I_i} = \mathrm{INT}\left[\mathrm{I_{min}} + \mathrm{r}\left(\mathrm{I_{max}} - \mathrm{I_{min}}\right)\right] \quad \mathrm{i} = 1,...., \mathrm{n} \qquad (3)$$

where; the term r represents a random number between 0 and 1, I_{min} is equal to 1 and I_{max} is the total number of values in the discrete set respectively. n is the total number of design variables.

Step 3 Moving toward the leader: New hunters’ positions are generated by moving toward the leader hunter.

$$\mathrm{I_i^{'}} = \mathrm{I_i} + \mathrm{r\ MML}\left(\mathrm{I_i^L} - \mathrm{I_i}\right) \qquad \mathrm{i} = 1,...., \mathrm{n} \qquad (4)$$

where; I_i^L is the position value of the leader for the *i-th* variable.

Step 4 Position correction-cooperation between hunters: After moving toward the leader, hunters tend to choose another position to conduct the `hunt' efficiently, i.e. better solutions. Position correction is performed in two ways, one of which is real value correction and the other is digital value. In this study real value correction is employed for the position correction of hunters.

$$I_i^{j'} \leftarrow \begin{cases} I_i^{j'} \in \left\{ I_i^1, I_i^2, \ldots, I_i^{HGS} \right\} \textit{with proba bility HGCR} \\ \text{INT } (I_i^{j'} = I_i \pm Ra) \quad \textit{with proba bility (1-HGCR)} \end{cases} \tag{5}$$

Step 5 Reorganizing the hunting group: Hunters must reorganize themselves to get another chance to find the global optimum. If the difference between the objective function values obtained by the leader and the worst hunter in the group becomes smaller than a predetermined constant (ε_1) and the termination criterion is not satisfied, then the group reorganized. By employing the Eq. 6, leader keeps its position and the others randomly select positions.

$$I_i^{'} = I_i^{L} \pm r \left(\max(I_i) - \min(I_i) \right) \alpha \, (-\beta \text{ EN}) \tag{6}$$

Where; $I_i^{\,L}$ is the position value of the leader for the *i-th* variable, *r* represents the random number between 0 and 1, $min(I_i)$ and $max(I_i)$ are min. and max. values of variable I_i, respectively, *EN* refers to the number of times that the hunting group has trapped until this step. α and β are determine the convergence rate of the algorithm.

Step 6 Termination: The steps 3 and 5 are repeated until a pre-assigned maximum number of cycles is reached.

5. DESIGN EXAMPLE

Optimum design algorithm presented is used to design a cellular beam with 12-m span shown in Figure 2. The beam is expected to carry the uniform dead load of 1.5 kN/m^2 and a live load of 2.5 kN/m^2 in addition its own dead weight. The upper flange of the beam is laterally supported by the floor system that it supports. The maximum displacement is limited to 34 mm. The modulus of elasticity is 205 kN/mm^2 and design strength of steel is 355 MPa.

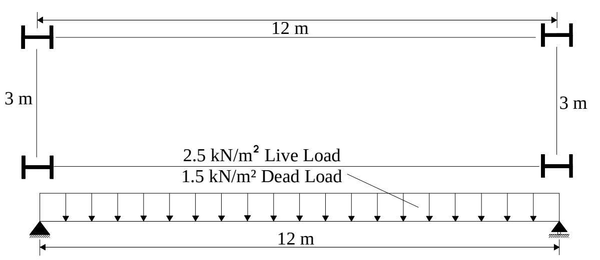

Figure 2. Loading of 12-m span cellular beam

The design example is separately solved by hunting search (HSM) and particle swarm (PSO) [4]. The size of the initial population and the maximum number of generations are kept the same in HSM and PSO. The result of the sensitivity analysis carried out for the HSM parameters is given in Table 1.

Table 1. Limiting width to thickness ratios

Method	UB-Section	Diameter	NH	Weight
HSM	457×152×52	581mm	17	554.40kg
PSO	457×152×52	563mm	17	562.81kg

It is apparent from the table that HSM produces the least weight for cellular beam which is equal to 554.4 kg. The maximum value of the strength ratio is 0.98 which is almost upper bound. This reveals the fact that the strength constraints are dominant in the problem. HSM algorithm presented selects 457×152×52 UB section for the root beam. The optimum cellular beam should be produced such that it should have 17 circular holes each having 581 mm diameter. PSO produces 562.81 kg weight for this design example. The design history curve for HSM and PSO techniques is shown in Figure 3. It is apparent from the figure that PSO method performs better convergence rate than HSM technique but HSM method finds the better solution in this design problem.

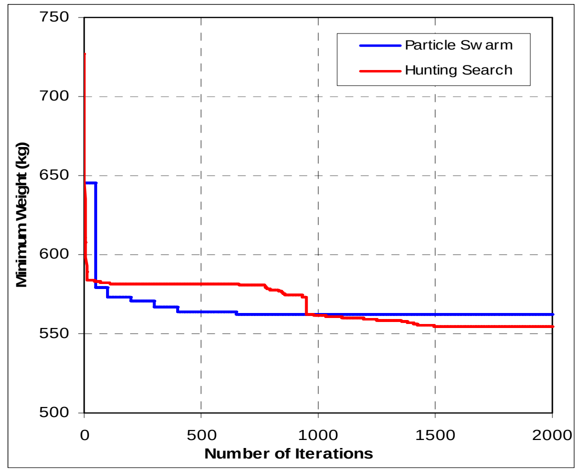

Figure 3. Design History Graphic of 12-m Cellular Beam

6. CONCLUSIONS

This study concerns with the application of a hunting search algorithm to the optimum design of cellular beams. The design algorithm is mathematically simple but effective in finding the solutions of optimization problems. Fly-back mechanism is employed for handling the problem constraints and feasible ones being candidate solutions to give the minimum weight are determined. A cellular beam example is designed to illustrate the efficiency of the algorithm. The same example is also solved with PSO to demonstrate the robustness of the proposed algorithm. Comparison of the optimum designs attained by HSM and PSO clearly shows that the HSM outperforms the latter in the second particular design problem. In view of the results obtained, it can be concluded that the HSM is an efficient and robust technique that can successfully be used in optimum design of cellular beams.

7. REFERENCES

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