Australian Journal of Basic and Applied Sciences, 5(8): 1428-1434, 2011
ISSN 1991-8178

Using Particle Swarm Optimization for Minimization of Moment Peak in Structure

[1]Ali Ghoddosian, [2]Mojtaba Sheikhi

[1,2]Department of Mechanical Engineering, University of Semnan, Semnan, Iran

Abstract: Frame structures are widely used in practical engineering; the structural behaviors are substantially influenced by the bending moment involved in the flexural members. For this purpose, in this study, particle swarm optimization and finite element method are employed in shape structural optimization models to minimize the maximum bending moment. Particle swarm optimization is a novel meta-heuristic optimization algorithm and is powerful, efficient and is very simple to solve the combinatorial shape optimization problems. In this paper, at first maximum bending moment in frame structure by using finite element method is investigated and then particle swarm optimization is applied to minimize the maximal bending moment. Numerical examples are provided to demonstrate the applicability and capability of the present method. The results indicate the effectiveness of the proposed algorithm and its ability to find optimal shape of structure for minimizing the maximum bending moment problem.

Key words: Shape optimization, Finite Element Method (FEM), Bending Moment, Particle Swarm Optimization (PSO)

INTRODUCTION

The shape or geometry optimization in structural problem consists in looking for the geometry that minimizes an objective function such as mass or compliance and etc, subject to mechanical constraints. It is a traditional field in structural design, and there are many books and surveys dealing with it and related fields (Haftka, R.T, Grandhi, RV., 1986; Sokolowski, J, Zolesio, JP. 1992; Kwak, BM. 1994; Bendsøe, M.P. 1995; Pedersen, P. 2000).

Frame structures are widely used in practical engineering, especially in building constructions, aircraft, etc. In many engineering design, the bending moment has always been one of the major concerns to a designer. Therefore, minimizing the maximal bending moment (MBM) is of paramount interest in a true structure design. In the past decades, the majority of the related optimization work has been conducted for the structural weight minimization (Erbatur, F., Al-Hussainy, M.M., 1992; Sui, YK., Wang, XC. 1997; Pezeshk, S., 1998; Missoum *et al.,* 2002; Isenberg *et al.,* 2002; Lamberti L., C. Pappalettere, 2004). Usually the sectional properties, such as the areas or moment of inertia, of the members are chosen as the design variables, and displacement or stress limitations are referred to as design constraints. During the solution process, the bending moment in members is not under control. In view of this, it is therefore desirable to find an appropriate procedure of design optimization on the criterion of minimizing the MBM in a given to benefit a practical design.

In the past of the existing literature reveals that the optimal design of the bending moment has not been explored extensively, and relatively few publications are available (Imam, M.H., Al-Shihri, M., 1996; Steven *et al.,* 2000; Xu, L., 2001; Perezzan, J.C., Hernandez, S., 2003; Wang, D., 2006; Wang, D., 2007; Wang *et al.,* 2002; Greiner *et al.,* 2004; Kaveh *et al.,* 2010). Therefore, more efforts are still required, in both analytical and application aspects, toward the design optimization of a structure for minimization of the MBM. In fact, engineering experience and numerous experiments have plentifully demonstrated that the structural responses are much more sensitive to its shape or configuration variation. Compared with the size adjustment, structural shape modification, in spite of its complexity, can provide a substantial redistribution of the internal forces in the structure, change the pattern of the force mainly transmitted in each member (Steven *et al.,* 2000), and consequently, reduce the MBM considerably. Thus, this is a challenging category of the structural optimization problems encountered in the field.

For this reason, this research presents a study to minimize the MBM in a frame structure by means of its shape optimization. In this paper, by using PSO, the nodal coordinates of frame structure, for minimizing the MBM, is found. To implement the solution process, finite element method is employed to calculate the MBM in structure.

Corresponding Author: Mojtaba Sheikhi, Department of Mechanical Engineering, University of Semnan, Semnan, Iran
E-mail: mojtabasheikhi@gmail.com

It is essential to point out that an important character of the MBM may very often alter its locus from one point to another during the optimization process. Therefore, the objective function may change its value abruptly with the design progression. Sometimes, its sign may change from positive to negative or vice versa as the design proceeds. Thus, the objective itself is non-smooth and implicit with regard to the design variables. These difficulties or complexities have, to a certain extent, seriously hindered the wide research for the optimal design of the bending moment. So using the first or higher order optimization method such as using sensitivity analysis (first order) that require the derivatives of the objective function and constraints is make difficulty and too complex to be handled with mathematical programming methods. For this reason, PSO is adopted in this paper. PSO is zero order optimization method, and is very suitable and powerful in obtaining the solution of combinatorial optimization problems.

Problem Definition:

For general frame structure consisting of flexural members, structural performance subjected to several loads has to be considered, and the MBM for these loads is taken into account for minimization. Thus, the objective of the optimization problem is to minimize the maximum moment in all the members under multiple load cases. In many cases, constraints on design variables, which directly specify the bounds of the nodal position, are often encountered in a shape optimization process, besides some nodal coordinates are linked so as to retain the structural symmetry or limit the number of design variables. Therefore the optimization problem can be stated mathematically as *Eq*. (1).

$$Minimize\ \left|MBM\right|$$

$$S.to:\begin{cases} S_{Li} \le S_i \le S_{Ui},\ (i=1,\ldots,k) \\ S_j = f(S_i),\ (j=1,\ldots,l) \end{cases} \tag{1}$$

Where " $\left|MBM\right|$ " is the maximum absolute value of the bending moment in the structure, S_i and S_j are the coordinates of independent and dependent nodal coordinates; S_{Li} and S_{Ui} are the lower and upper bounds on the independent coordinates respectively. k and l are the number of independent and dependent nodal coordinates.

The absolute MBM in *Eq*. (1) does not refer to the response measured at a single point; and may frequently migrate from one point to another in the solution process. Consequently, abrupt changes may often occur in the objective function as well as in its derivative with the design progression, which then brings a practical obstacle into first or higher order optimization algorithm and deteriorates the solution convergence.

Minimizing MBM by PSO:

Heuristic algorithms such as genetic, ant colony, simulated annealing and particle swarm optimization have found application in many optimization problems in the last decade. These stochastic search techniques make use of the ideas taken from nature and do not suffer the discrepancies of mathematical programming based optimum design methods. The basic idea behind these techniques is to simulate the natural phenomena such as survival of the fittest, swarm intelligence and the cooling process of molten metals into a numerical algorithm. These methods are non-traditional search and optimization methods and they are very suitable and powerful in obtaining the solution of combinatorial optimization problems. They do not require the derivatives of the objective function and constraints and they use probabilistic transition rules not deterministic rules.

The PSO algorithm was initially developed by Kennedy and Eberhart, (1995). It is an optimization algorithm based on the motions of flocking birds and schooling fish. In it, a group of particles traverse the problem space. At time t, each particle has velocity V_t and position X_t. For each iteration, they change velocity(V_t) so as to move toward the best point they have visited (P_b), and to move toward the best point they and their neighbors have ever visited (G_b). The degree to which the particle moves toward each of these points is determined randomly, from a uniform probability distribution (r_1, r_2), the degree of communication varies with different implementations of PSO Engelbrecht, A., (2007); In this paper, it is assumed that all particles communicate with each other, though other topologies in which communication is limited to several neighbors have been shown to be more effective. The general behavior of the PSO algorithm is described in Algorithm 1; the general form of the position and velocity update for the canonical PSO are given in *Eq.*(2) and *Eq.*(3) respectively.

$$X_{t+1} = X_t + V_{t+1} \tag{2}$$

$$V_{t+1} = \chi(\omega V_t + C_1 r_1 (X_t - P_b) + C_2 r_3 (X_t - G_b)) \tag{3}$$

Algorithm 1: General process for Particle Swarm Optimization

For each time-step
For each particle
Update particle position X_t
Calculate particle fitness *f(x)*
Update P_b, G_b
End For
End For

For these tests, we use the variant of the Particle Swarm Optimization algorithm formulated by Clerc and Kennedy, (2002),. In this case, an overall 'constriction factor' (χ) controls the rate of convergence of the search, rather than the inertia weight (ω). The constants in *Eq*. (3) are given the values: χ = 0.729, ω = 1.0, ψ = 4.1, C_1 = C_2 = 1.0, as proposed by Clerc and Kennedy, (2002). This variant of PSO is simple to implement, as variants that use inertia weight to control the search will often vary this weight over the progress of the algorithm. It is also effective.

In this paper, first the MBM in frame structure is determined by using FEM Singiresu S. Rao., (2004) . Then, on the basis of the PSO algorithm, the nodal positions of frame structure are meved to reduce the MBM most effectively.

Simulation Results and Discussions:

In this section, three shape optimization examples were utilized to evaluate the effectiveness and performance of the proposed PSO algorithm. The final results are compared to the solutions of other methods to demonstrate the efficiency of the present approach. Resulting solutions show that shape optimization can make a significant reduction of the bending moment in a given structure. In the design process, the layout of the structure is initially determined and remains invariable.

Two Beam Frame:

In this example, a two-beam frame structure subjected to two loads as shown in fig. 1, is considered. The cross sectional area and Young's modulus of all members are A=7.26 cm^2 and E=210 Gpa respectively.

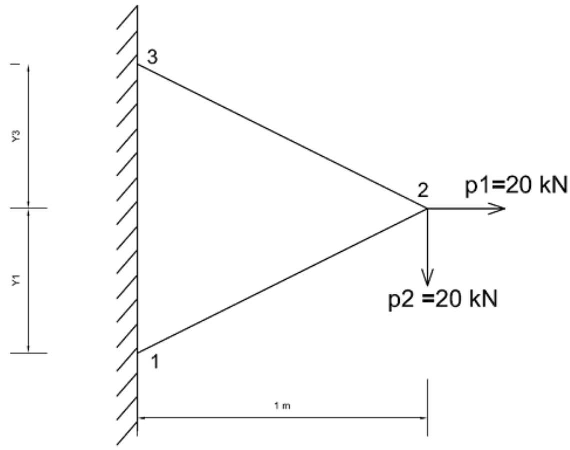

Fig. 1: a simple frame structure with two members

Nodes 1 and 3 can be independently moved in vertical support but these nodal coordinates' needs to be relocated symmetrically to minimize the MBM.

Fig. 2, show the convergence history for the mean and best results of all particles with PSO. Optimal shape design of two member frame structure for minimization of the MBM obtained at y=0.9979 m with the MBM= 66.5823Nm.

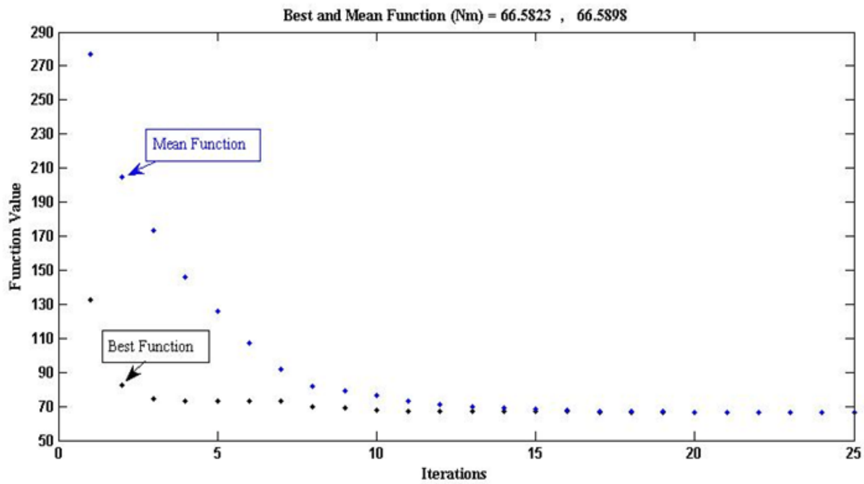

Fig. 2: Mean and best results of all particles versus iteration

Michell Type structure:

Michell type structure is a standard problem for evaluate the efficiency and validity the structural optimization methods. Recently, it was investigated in shape optimization on the criterion of the weight (Isenberg *et al.,* 2002; Wang *et al.,* 2002) for truss and MBM minimization (Wang, 2007) with frame model. In fig. 3, shows the general configuration of the Michell structure with the external load P=200 kN.

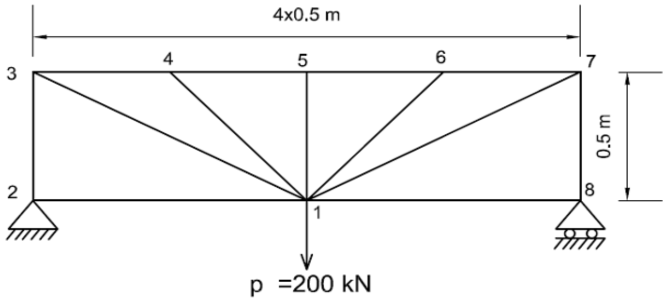

Fig. 3: general configuration of the Michell type structure

The cross sectional area and Young's modulus of all members are A=4.9 cm^2 and E=210 Gpa. Assume coordinate of nodes 1, 2 and 8 remained fixed while the coordinate of nodes 3, 4, 5, 6 and 7 can move in both horizontal and vertical directions, respectively. During the design process, the symmetry of the structure is maintained. Therefore, only five nodal coordinates need to be redesigned independently ((X_1, Y_1) = (0, 0), X_3=-X_7, Y_3=Y_7, X_4=-X_6, Y_4=Y_6, Y_5).

In fig. 4, and fig. 5, the optimal configuration and evolutionary history of the MBM is illustrated respectively. In this numerical example, the MBM in general configuration (fig. 3.) is 4299.7 Nm. Table (1) shows the best MBM for present method and reference (Wang, 2007). The optimal MBM decreases about 19.1% and 84.8% with respect to reference (Wang, 2007) and general configuration (fig. 3.) respectively.

Table 1: Optimal design comparison for Michell type structure

	Sensitivity analysis (Wang, 2007)	Present method
MBM (Nm)	807.0	653.122

Bridge Structure:

This example is a frame structure, loaded by five concentrated forces together as shown in fig. 6; the members are classified into three groups. The cross sectional area on the upper chord is A_u=27.49 cm^2, the lower chord is A_l=150 cm^2 and the five columns are A_c=19.63 cm^2. Suppose Young's modulus is E=210 Gpa. An external force p=100 kN is applied downward at each nodes on the lower chord. During the optimization process, nodes on the lower chord remain fixed while nodes on the upper chord will be shifted vertically. To maintain the structure symmetric, only three independent coordinate variables need to be redesigned ((X_1, Y1) = (0, 0), Y_3=Y_{11}, Y_5=Y_9, Y_7). In fig. 7, the optimal configuration is illustrated.

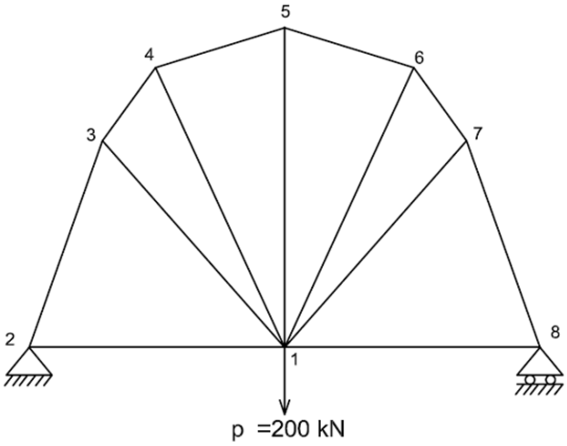

Fig. 4: optimal configuration of the Michell type structure

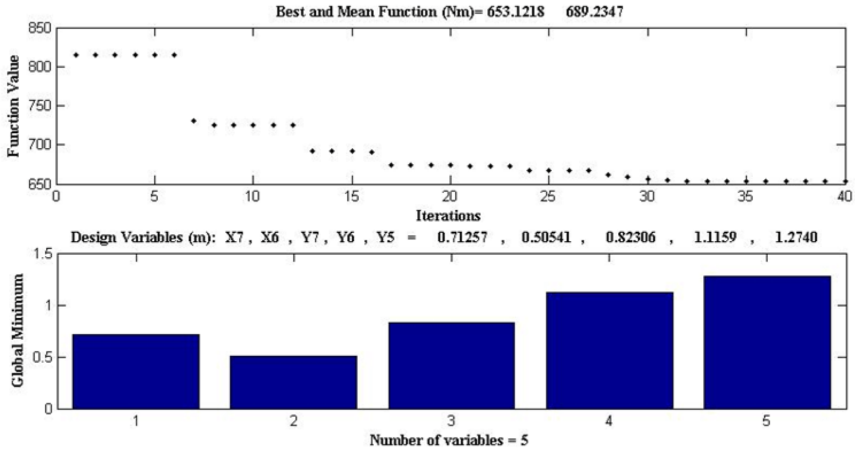

Fig. 5: evolutionary history of the MBM for Michell type structure

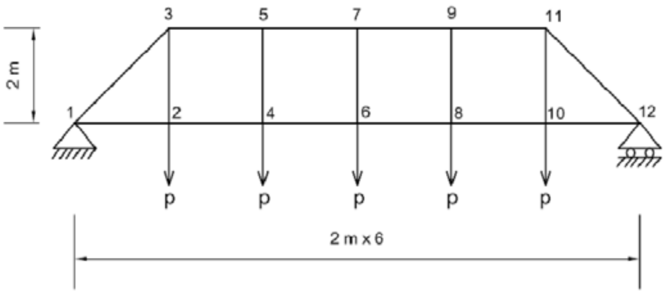

Fig. 6: general configuration for bridge structure

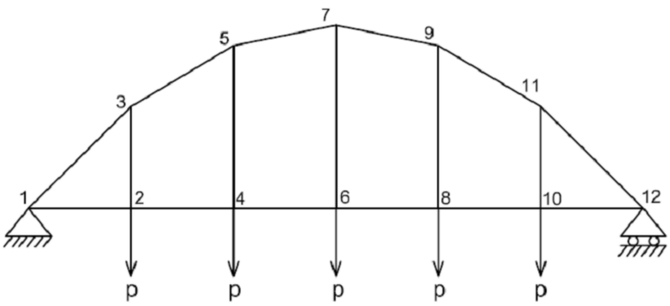

Fig. 7: optimal configuration for bridge structure

Fig. 8, plots the evolutionary history of the MBM. In table (2) the MBM for present method and reference (Wang, 2007) are listed. The optimal MBM decreases about 36.6% and 98.1% with respect to reference (Wang, 2007) and general configuration (fig. 6, MBM=147.64 kNm) respectively.

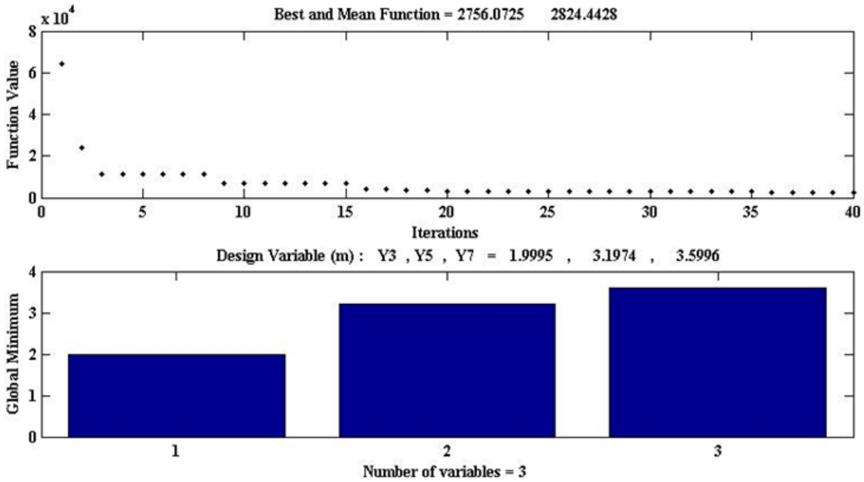

Fig. 8: Evolutionary history of the MBM for bridge structure

Table 2: Optimal design comparison for bridge structure

	Sensitivity analysis Wang, (2007)	Present method
MBM (kNm)	4.35	2.76

Conclusions:

In practical engineering designs, the bending moment is always an important factor in the proper design of a frame structure. Thus, reducing the MBM in the structure can significantly improve its behavior, and usually decrease the normal stress in each of the members. In this study, MBM in frame structure with a novel heuristic optimization method (PSO) is minimized. For this purpose, shape optimization of frame structure is a very effective approach to reduce the MBM by means of changing nodal coordinates. Three design examples are considered to illustrate the efficiency of the present algorithm. Results shown that, PSO is mathematically quite simple and more effective in finding the optimal shape of frame structures with respect to the other methods. It does not need any initial starting values for the design variables so there is no sensitivity to the population size of candidate solutions for the design problem. In this algorithm, constraints are considered independently and it is not necessary for the given objective function that to be continuous.

ACKNOWLEDGEMENT

The Second author is grateful for the financial support provided by Semnan University.

REFERENCES

Bendsøe, M.P., 1995. Optimization of structural topology, shape and material. Berlin, Heidelberg, New York: Springer.

Clerc, M. and J. Kennedy, 2002. ”The particle swarm-explosion, stability, and convergence in a multidimensional complex space,” IEEE Transactions on Evolutionary Computation, 6(1): 58-73.

Engelbrecht, A., 2007. computational intelligence, John Wiley & sons, ltd.

Erbatur, F., M.M. Al-Hussainy, 1992. “Optimum design of frames”, Comput Structures, 45: 887-891.

Greiner, D., J.M. Emperador, G. Winter, 2004. “Single and multi objective frame optimization by evolutionary algorithms and the auto-adaptive rebirth operator”, Comput. Methods Appl. Mech. Engrg, 193: 3711-3743.

Haftka, R.T., R.V. Grandhi, 1986. “Structural shape optimization – A survey”, Comput Methods Appl Mech Eng., 57: 91-106.

Isenberg, V., D. Pereyra, Lawver, 2002. “Optimal design of steel frame structures”, J. Appl. Num. Math., 40: 59-71.

Imam, M.H., M. Al-Shihri, 1996. “Optimum topology of structural supports”, Comput Struct, 61: 147-154.

Kaveh, A., B. Farahmand Azar, A. Hadidi, F. Rezazadeh Sorochi, S. Talatahari, 2010. “Performance-based seismic design of steel frames using ant colony optimization”, J. Constructional Steel Research, 66: 566-574.

Kennedy, J. and R.C. Eberhart, 1995. “Particle swarm optimization,”’ presented at the IEEE International Conference on Neural Networks, Piscataway, NJ. 1942-1948.

Kwak, B.M., 1994.“A review on shape optimal design and sensitivity analysis”, Struct Eng/Earthq Eng, 10(4): 159-74.

Lamberti, L., C. Pappalettere, 2004. “Improved sequential linear programming formulation for structural weight minimization”, Comput Methods Appl, 193: 3493-3521.

Missoum, S., Z. Gurdal, LT. Watson, 2002. “A displacement based optimization method for geometrically nonlinear frame structures”, Struct Multidiscip Optim, 24: 195-204.

Pedersen, P., 2000. “On optimal shapes in materials and structures”, Struct Multidisc Optim, 19: 169-82.

Pezeshk, S., 1998. “Design of framed structures: An integrated non-linear analysis and optimal minimum weight design”, Internat J Numer Methods Engrg, 41: 459-71.

Perezzan, J.C., S. Hernandez, 2003. “Analytical expressions of sensitivities for shape variables in linear bending systems”, Adv Eng Softw, 34: 271-278.

Singiresu S. Rao., 2004. the element method in engineering 4th edition, Elsevier Science & Technology Books.

Sokolowski, J., J.P. Zolesio, 1992. Introduction to shape optimization – Shape sensitivity analysis, Berlin, Heidelberg, New York: Springer-Verlag.

Steven, G., O. Querin, Y.M. Xie, 2000. “Evolutionary structural optimisation (ESO) for combined topology and size optimisation of discrete structures”, Comput Methods Appl Mech Eng, 188: 743-54.

Sui, Y.K., X.C. Wang, 1997. “Second-order method of generalized geometric programming for spatial frame optimization”, Comput Methods Appl Mech Eng, 141: 117-123.

VanKeulen, F., R.T. Haftka, N.H. Kim, 2005. “Review of options for structural design sensitivity analysis”, Part 1: Linear systems. Comput Methods Appl Mech Eng, 194: 3213-43.

Wang, D., 2006. ”Optimal design of structural support positions for minimizing maximal bending moment”, Finit Elements in Analysis and Design, 43: 95-102.

Wang, D., 2007. “Optimal shape design of a frame structure for minimization of maximum bending moment”, Engineering Structures, 29: 1824-1832.

Wang, D., W.H. Zhang, J.S. Jiang, 2002. “Truss shape optimization with multiple displacement constraints”, Comput Methods Appl Mech Eng, 191: 3597-3612.

Xu, L., 2001. “On the minimum–maximum bending moment and the least-weight design of semi-rigid beams”, Struct Multidiscip Optim, 21: 316-321.