SIZING OPTIMIZATION OF FRAME TUBE STRUCTURSSUBJECTED TOWIND INDUCED LOADING BY MINE BLAST ALGORITHM

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ABSTRACT

Structural design of tall buildings is an engineering challenge due to considerable difference between several possible alternatives. Such asearch space is too complicated to be perfectly handled by a simple manual design. Alternatively, computerized sizing optimization as a systematic solution is concerned here using meta-heuristic methods. The capability of these methods to search for the global optimums in discrete problems is concerned to achieve the final practical design using any available list of structural sections.In this regard, the optimization problem is formulated to achieve minimal structural weight in tall buildings against gravitational and lateral loadings under codified stress and drift constraints in accordance with the Iranian codes of practice for steel structures (Part 6 & Part 10). Examples of three dimensional rigid frames are treated via two types of modeling;one by rigid floorswithoutrotationaldegreesoffreedomandthe other with both translational and rotational degrees of freedom. A number ofmeta-heuristic algorithmsarethus employed via comparative study of their performance in the current sizingproblem; they are *Harmony Search,Particle Swarm Optimization*and recently developed*Mine Blast Optimization*. Considerable benefit in material cost minimization is obtained using these algorithms using tuned parameters. Asaresult, theeffectiveness of HS is concluded to be less than the other two. It isalso declaredthat the taller the building, the more computational effort is required to achieve proper convergence. Furthermore, sensitivity of MBO algorithm related to its parameters isalso evaluated.

INTRODUCTION

Over the last decades, various algorithms have been used to solve constrained engineering optimization problems. Some of these algorithms are based on numerical linear and nonlinear programming methods that require substantial gradient information and usually seek to improve the solution in the neighbourhood of a starting point. These numerical optimization algorithms provide useful strategies to obtain the global optimum using simplified and ideal models. Many real-world engineering optimization problems, however, are very complex in nature and quite difficult to solve. If a problem has more than one local optimum the result may depend on the selection of the initial pointthus the obtained optimal solution may not necessarily be the global optimum.

In contrary, meta-heuristic algorithms exhibit a common feature of over-passing local optima toward the global optimum using stochastic operators. Each of them, however, applies its special rules imitatingsome natural phenomena. These include the swarm behaviour such as in the*particle swarm optimization,* PSO,(Kennedy and Eberhart, 1995), musical process of searching for perfect state of harmony such as *Harmony Search*, HS(Lee and Geem, 2005) and the explosion in mine field in recently developed *Mine Blast Optimization*, MBO, (Sadollah et al. 2012, 2013).

The framed tube system is widely accepted as an economic solution for tall building structures over a wide range of building heights (Kwan, 1994). In its basic form, the system consists of closely spaced perimeter columns tied at deep spandrel beams of each floor to form a tubular structure. Therefore, such a system acts like a cantilevered box beam under lateral loads. As a result of the flexural and shear flexibilities of the frame members, the basic beam bending action of the framed tube is complicated due to “shear lag” phenomenon which increases axial stresses in some corner columns and decreases those in the inner columns affecting lateral stiffness of the structure.Thematteralso affects section classifying in optimization process and should be noted in column and beam classifications. Study of such a structural system via suitable models isrevealed by Movahed et al. 2014. In this paper, at first, a definition of the problem and algorithms arepresented, then design considerations and models are explained and at last final numerical results are reported.

PROBLEM DEFINITION AND FORMULATION

The objective function,$f(x)$, in the optimizing problem in this paper is total weight of structural members. For such aconstrained problem a penalty function is defined to calculate violation of the constraints which are to be satisfied as design requirements on (stress, drift, etc.) responses (Fourie et al. 2002). The following penalty function is employed here:

$$\tilde{f} = f(x) + \sum_{j=1}^{m} \varphi_j \left[g_j(x)\right]^2 \mu_j(g_j) \tag{1}$$

Where$g_j(x)$, stands for the$j$th member of penalty function (g) of a solution vector (x), and $\varphi_{j>0}$.

$$\mu_j(g_j) = \begin{cases} 0 & if \quad g_j(x) \le 0 \\ 1 & if \quad g_j(x) > 0 \end{cases} \tag{2}$$

Structural optimization problem with discrete variables can be formulated as a non-linear programming problem (NLP). For sizing optimization of steel structures, cross-section areas and the other properties of the members are considered as primary design variables. However, integer section indices are utilized here as linked discrete variables (Arora,2004). Such a design variable is chosen from a list of discrete cross-sections based on production standards. These functions, programs of structural analysis and optimization algorithms, all are codified in MATLAB software.

MINE BLAST ALGORITHM

The idea of the MBO algorithm is based on observation of a mine bomb explosion, in which the thrown pieces of shrapnel collide with other mine bombs near the explosion area resulting in their explosion. Hence, the goal is to find the mines, while the most important is to find the one with the most explosive effect located at optimal point X^*which can cause the most casualties (minor max $f(x)$ per X^*). When a mine bomb is exploded, it spreads many pieces of shrapnel and the casualties ($f(x)$) caused by each piece of shrapnel are calculated. Each shrapnel piece has definite directions and distances to collide with other mine bombs.

The prescribed algorithm start with one or more initial points called first shot points represented byX_0^f. The super script f refer to the number of first shot points. Duo to experience of the method author, large number of first shot points, did not offer significant improvement in the optimization process for any problem and so one first shot point is utilized in the present work.

To start with feasible first shot point, define new first shot point as below:

$$X_0^{new} = LB + rand \times (UB - LB) \tag{3}$$

WhereX_0^{new}, LB and UB are the new generated first shot point using algorithm, lower and upper bounds of the problem, respectively.$rand$is a uniformly distributed random number. Suppose that X is the current location of a mine bomb given as:

$$X = \{X_m\}, \quad m = 1,2,3,\cdots,N_d \tag{4}$$

In which N_d is the search space dimension equal to the number of independent variables. Consider that N_s shrapnel pieces are produced by the mine bomb explosion causing another mine to explode at X_{n+1} location:

$$X^f_{n+1} = X^f_{e(n+1)} + exp\left[-\left|\frac{\overline{M^f_{n+1}}}{D^f_{n+1}}\right|\right]X^f_n, \quad n = 0,1,2,3,\ldots \tag{5}$$

Where$X^f_{e(n+1)}$, D^f_{n+1} and M^f_{n+1} are the location of exploding mine bomb collided by shrapnel, the distance and the direction (slope) of the thrown shrapnel pieces in each iteration, respectively. The location of exploding mine bomb $X^f_{e(n+1)}$ is defined as:

$$X^f_{e(n+1)} = d^f_n \times rand \times \cos(\theta) \tag{6}$$

Where θ is the angle of the shrapnel pieces which is a constant value and is calculated using$\theta = 360/N_s$. The exponential term in Eq. (5) is used to improve the obtained blast point by influencing the information from previous solutions (X^f_n). The distance D^f_{n+1} and the direction of shrapnel pieces M^f_{n+1} are defined as:

$$D^f_{n+1} = \left|\sum_{i=1}^{m}(X_{it} - X_{i(t-1)})^2\right|^{1/2} \qquad t = \mu,\ldots,N_{LastIter} \tag{7}$$

$$M^f_{n+1} = \frac{F_t - F_{t-1}}{D^f_{n+1}} \qquad t = \mu,\ldots,N_{LastIter} \tag{8}$$

Where F is the function value for the$X$. To calculate the initial distance for each shrapnel pieces $d_0 = (UB - LB)$ in each dimension is used. The algorithms iterates up to the pre-assigned $N_{LastIter}$. In order to conduct exploration of the design space at smaller and larger distances, the exploration factor (μ) is introduced. This constant is used in the early iterations of the algorithm and is compared with an iteration number (k). If it is higher than k, then the exploration process begins. The distance of thrown shrapnel pieces in exploration phase changes as below:

$$X^f_{e(n+1)} = d^f_n \times (|randn|)^2 \times \cos(\theta) \tag{9}$$

A larger value for the exploration factor (μ) makes it possible to explore more remote regions, thus the value of μ determines the intensity of the exploration. To increase the global search capability of the algorithm, distance of the shrapnel pieces are reduced gradually to allow the mine bombs search the probable global minimum location. The reduction in d^f_n is given as:

$$d^f_n = \frac{d^f_{n-1}}{\exp(k/\alpha)}, \quad n = 1,2,3,\ldots \tag{10}$$

Where α and k are the reduction constants and the iteration number index. The choice of α asa user-defined parameter depends on the complexity of the problem. The role of α is to reduce the distance of each shrapnel piece adaptively according to Eq. (10).

WIND LOAD CRITERIA

Regarding considerable influencing factors related towindloads, there are appropriate codified provisions which have been recommended by building codes. Increasing wind force in height and similar frequency content in tall buildings and major frequency band of wind excitation show importance of theresearch. According to Iranian national building code, part 6, for buildings with height to effective width ratio of 4 or more or height above 60 meters and also structures with main frequency in range 0.25Hz-1Hz,wind loading must be applied dynamically. Dynamic state parameters contain some feature of structure and wind stream such as turbulence intensity, height, natural vibration frequency and damping ratio of the structural system. Wind pressure or suction on each outer surface of structure is:

$$p = I_w . q . C_e . C_g . C_p \tag{11}$$

Where I_w, q and C_p are importance factor, basic wind pressure for target region and outsider pressure factor, respectively.$C_g$addressesgust effect factor and C_e stands for exposure factor. In the wind resistance related codes, there are advises to test some different cases of wind loading and take the most critical case as design loading base.Fig.1 demonstrates such states of loading due to Iranian code of practice.

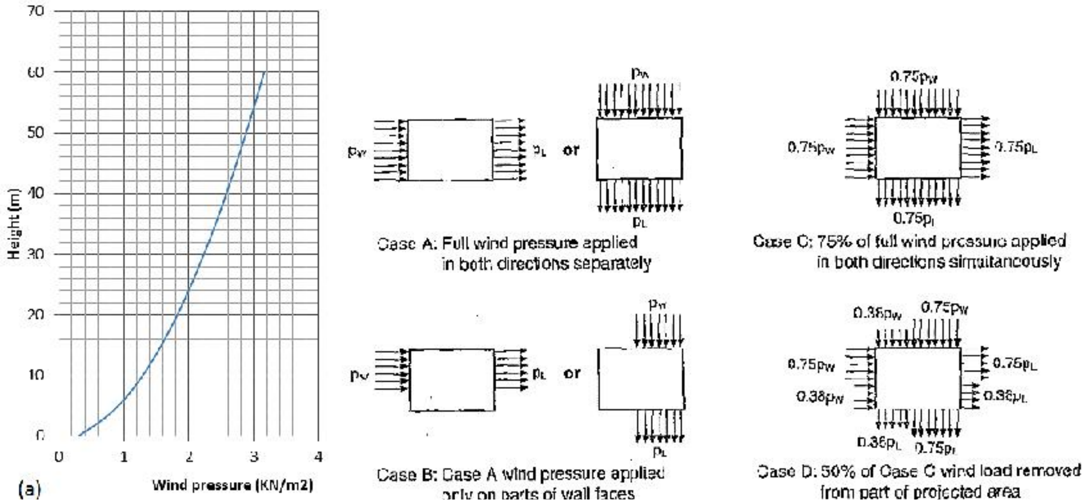

Figure 1. (a) General display of wind pressure against height at study region for 20-storey structure; (b) Different wind load cases in Iranian building code

NUMERICAL RESULTS

The structural models in this research consist of three steel frames in 10, 20 and 30-storey forms. The plan and a resistant side frame of 20-storey model are shown in Fig.2. It is assumed that interior beam-column joints in structure are hinged. Lateral load resistant system is only perimeter frames and linear allowable stress design methodology is applied.

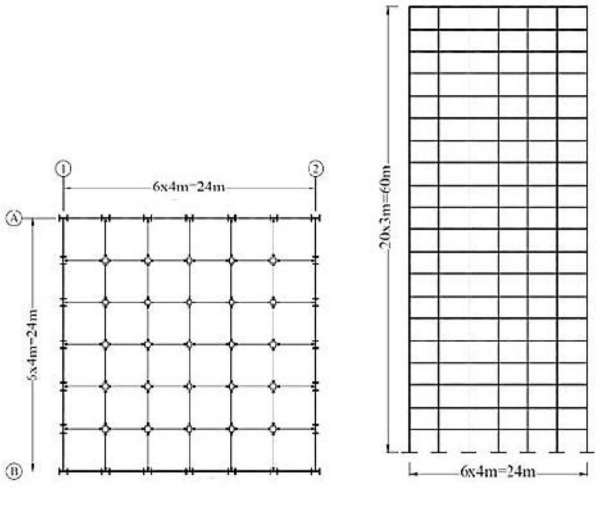

Figure 2.Structural models: General plan and elevation of 20-storey building (Movahed et al. 2014)

The dead and live loadsare considered 0.5 $ton/m^2$and 0.2 ton/m^2at floors, respectively. Design considerations and load cases have been selected according to Iranian national building code, part 10. Different load cases with wind load phrase are selected.

The results of a side frame as main lateral force resistance system of the treated tube structures are reported, hereinafter. In Fig.3a comparison of convergence rate and performance in finding better solutionsfor three prescribed algorithms are presented. Mine blast algorithm has revealed good convergence rate and considerably better results thanHS and PSO. Although effective parameters in particle swarm algorithm and harmony search algorithm were tuned many times, still MBO results are better comparing the results in Fig.3a where 2 trials of HS and PSO methods is shown.

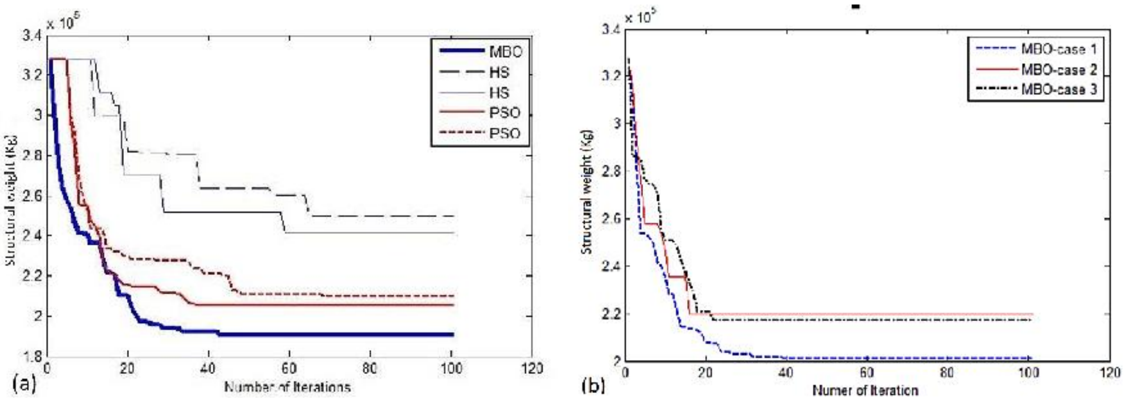

Figure 1.Comparison of results; (a) MBO, PSO and HS algorithms of 20-storey model; (b) MBO results with different effective parameters for 20-storey model

When meta-heuristic methods are evaluated, one of the most aspects of specific method is experimental effective parameters of method. Fig.3b displays the effect of tuning these parameters for MBO method. According to it, in the three cases, results either in convergence rate orquality of final optimum are different. Table1 gives correspondingeffective parameters in each case; where *R*standsfora*reduction distance marker*. Ifvariation of function values in the current iteration is more than *R*, distance of shrapnel in next iteration reduced in order to concentrate on the optimal points.Assumingthe maximum iteration number of$N_{LastIter}$, « in Table 1denotes the percentage of the iterations that algorithm are in the exploration phase.

Table 1: MBO effective parameters in this study

	d_0	Exploration factor (μ)	R	Shrapnels number
Case 1	$(UB - LB)/2$	$20\ \%\ 0f\ N_{LastIter}$	300 kg	11 piece
Case 2	$(UB - LB)/4$	$50\ \%\ 0f\ N_{LastIter}$	700 kg	11 piece
Case 3	$(UB - LB)/8$	$10\ \%\ 0f\ N_{LastIter}$	1000kg	11 piece

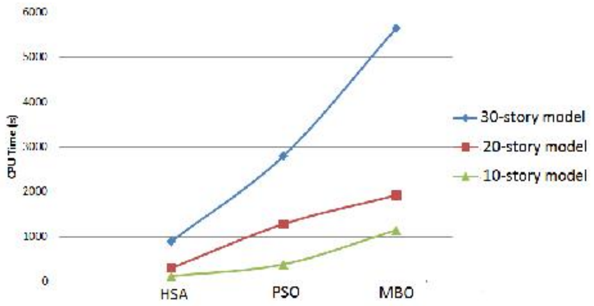

Figure 4.CPU time for three studied algorithms at 10-storey, 20-storey and 30-storey models

In order to study time-complexity of the treated algorithms, their corresponding elapsed times are compared in Fig.4 for any of the 10, 20 and 30 storey examples. Regarding previous Figure, it is concluded that MBO requires more computational effort to derive its superior quality results with respect to PSO. Similar conclusion is extracted for PSO with respect to HS with a further consideration that HS requires one more fitness evaluation in every its iteration, in spite of the other two algorithms.

As another issue, the effect of structural modeling on the results is investigated. In a three dimensional model, if the floors are taken rigid the amount of material required to resist the wind differs with the flexible floor model with rotational and transitional degrees of freedom at the corresponding connections. Consequent deformations and stresses in the structure will also be affected because rigid floors activate axial behavior of flange plane frames in frame tube structure.

Fig.5 shows results of some MBO trials with flexible floor modeling vs. a rigid floor model. As can be realized, less structural material is required in the optimal design of rigid floor model compared with those of the flexible floor models. That is, of course,required to compensate lower stiffness of the later model due to their hinged connections in comparison to higher stresses in rigid connections.

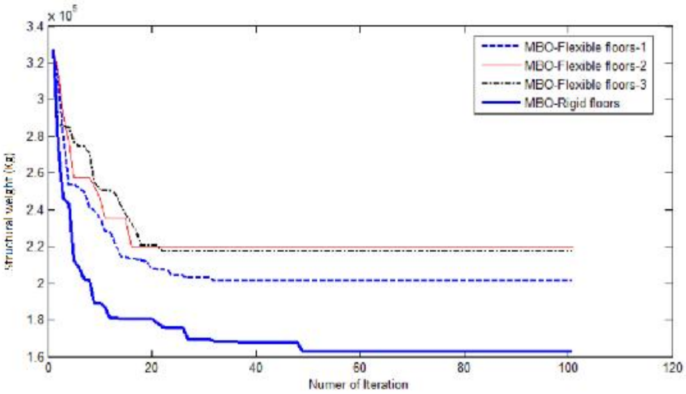

Figure 5. Floors flexibility and rigidity states

As an important criterion for structural design of tall buildings, overriding the drift constraint by the optimization is also concerned in the present work. Consider the maximum allowable drift by the applied code be (H/500) where “H” is the height of structure.

Fig.6 shows that such a constraint is activated in the 20 storey and 30 storey examples, however, in the 10 storey one stress ratios has reached their codified limits.Thus, stress of structural members is determinative in some models, while the drift constraint is critical in the others. It can also be noted that although the MBO has resulted in lighter structural designs, HS or PSOhave caused more values of maximal storey drifts.

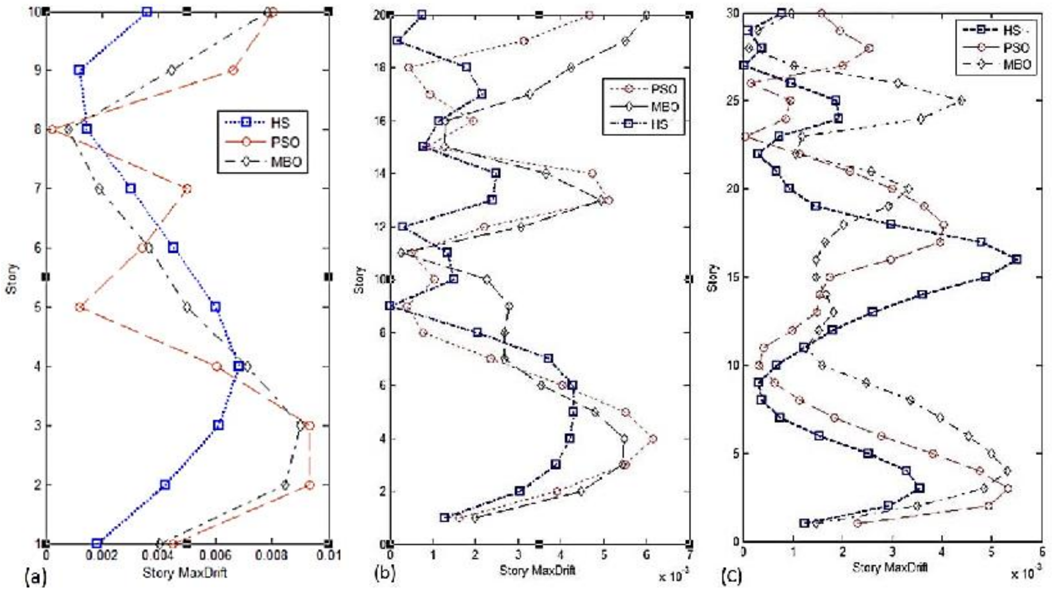

Figure 6.The maximum drift of stories; (a) 10-story model; (b) 20-storey model; (c) 30- storey models

CONCLUSION

Sizing optimization of frame tube structures subjected to codified gravitational and windload combinationshave been studied here utilizing proper discrete space problem formulation. Integer coding of design variables make it possible to accurately choose between structural sections available from practical lists. As a recent optimization tool, MBO performance was evaluated and compared in this problem compared with two well-known algorithms; i.e., HS and PSO. After suitable parameter tuning, they are applied to a set of low- to high-rise steel buildings using three dimensional analyses. Such a parameter tuning reveals the best results of MBO using the lowest reduction marker, moderate exploration factor and the highest initial bandwidth among 3 treated cases.

In the light of the current study on three steel building examples, it is observed that more structural material is required to withstand sway of wind loading in flexible floors than in rigid floor modeling. Additionally, drift constraint tented to be activated for higher examples while stress limits were critical for others. It is also found that MBO designs can better satisfy such code regulations even with lower amount of structural material than the other two algorithms, however, in charge of more computational effort.

REFERENCE

Arora JS (2004) *Introduction to optimum design,Elsevier*, US

Applied loads on buildings- Part 6, *Iranian national building code*, Tehran, Iran, 2013

Coull A andBose B (1975) Simplified analysis of framed-tube structures, *Journal of the Structural Division*, *101*(11): 2223-2240

EberhartRC and Kennedy J (1995, October) A new optimizer using particle swarm theory, In *Proceedings of the sixth international symposium on micro machine and human science* (Vol. 1, pp. 39-43)

Fourie PC andGroenwold AA (2002) the particle swarm optimization algorithm in size and shape optimization, *Structural and Multidisciplinary Optimization*, *23*(4): 259-267

Kwan AKH(1994) Simple method for approximate analysis of framed tube structures, *Journal of Structural Engineering*, *120*(4): 1221-1239

Kicinger R,Arciszewski T and DeJong K (2005) Evolutionary design of steel structures in tall buildings, *Journal of Computing in Civil Engineering*, *19*(3): 223-238

Lee KS andGeem ZW (2005) A new meta-heuristic algorithm for continuous engineering optimization: harmony search theory and practice, *Computer methods in applied mechanics and engineering*, *194*(36): 3902-3933

Movahed H, Meshkat-Dini A andTehranizadeh M (2014) SEISMIC EVALUATION OF STEEL SPECIAL MOMENTRESISTING FRAMES AFFECTED BYPULSE TYPE GROUND MOTIONS, *Asian Journal of Civil Engineering (BHRC)*, *15*(4): 575-585

Mahdavi M, Fesanghary M andDamangir E (2007) an improved harmony search algorithm for solving optimization problems, *Applied mathematics and computation*, *188*(2): 1567-1579

Perez RE andBehdinan K (2007) Particle swarm approach for structural design optimization, *Computers & Structures*, *85*(19): 1579-1588

Sadollah A, Bahreininejad A, Eskandar H andHamdi M (2013) Mine blast algorithm: A new population based algorithm for solving constrained engineering optimization problems, *Applied Soft Computing*, *13*(5): 2592-2612

Sadollah A, Bahreininejad A, Eskandar H and Hamdi M (2012)Mine blast algorithm for optimization of truss structures with discrete variables, *Computers & Structures*, 102: 49-63

Steel structures- Part 10, *Iranian national building code*, Tehran, Iran, 2008