Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 9 (19): 3502-3512, 2009
ISSN 1812-5654

Eccentricity Optimization of NGB System by using Multi-Objective Genetic Algorithm

H. Mosalman Yazdi and N.H. Ramli Sulong
Department of Civil Engineering, Faculty of Engineering, University of Malaya,
50603 Kuala Lumpur, Malaysia

Abstract: In this study, a new method for designing a particular braced system by using multi-objective genetic algorithm is proposed. This type of braced system, which is called non-geometric braced system are mostly used in seismic areas and it allows architects to have more openings in the panels. Non-straight diagonal member of this system introduces eccentricity and it is connected to the corner of the frame by a third member. In designing this system, designers often use trial and error method to locate the connection point of the brace elements by considering various parameters which affect the design such as opening and frame dimensions, cross section areas of brace elements and the location of brace element connection. Hence, finding the best connection point with maximum stiffness and minimum weight of brace elements with conventional methods is not trivial. In this study, a multi-object genetic algorithm is proposed in determining the best selection for connection point and also the brace elements' cross section area proportions which is the key rule in determining the stiffness of the system. Boundary equations are set by introducing feasible area to avoid improper individuals followed by utilization of some operators such as selection, mutation, crossover and elite genetic algorithm. Based on the plain aggregate approaches for transforming the objective vector in scalar, some modifications are proposed to assist designers in making decision on prioritizing between the frame stiffness and brace frame weight in their design.

Key words: Brace, seismic load, genetic algorithm, multi object

INTRODUCTION

Designing structures in regions subjected to seismic activities is based on the philosophy which expresses: First, the structure must behave elastically and protect relatively brittle non-structural components against minor earthquake ground shaking. Therefore, a structure should have sufficient strength and elastic stiffness to limit structural displacements, such as interstory drift. Second, the structure must not collapse in a major earthquake. For this case, significant damage of the structure and non-structural components is acceptable. In order to prevent structure from collapse and minimize the loss of life, it must have large energy dissipation capacity during large inelastic deformations. In general, structural systems which exhibit stable hysteretic loops perform well under the large inelastic cyclic loadings characteristics of major earthquakes. Such stable hysteric characteristics of a structure can be obtained provided that the structural members and joints are designed to posses sufficient ductility.

In general for medium and high rise buildings, steel structures are used extensively due to their excellent strength and ductility properties. Mostly steel structures are designed to resist the lateral load by using brace elements. In general, braces are divided into two groups: concentric and eccentric. Concentric braced systems are more desirable because of relative good stiffness, along with their easy construction and economy aspects. Hence, these important criteria make this group more common than eccentrically braced frames (Moghaddam *et al*., 2005). On the other hand, eccentric braces need more construction accuracy thereby, it decreases construction speed and needs more cost in spite of better stiffness performance and higher energy dissipation because they mainly yield in bending. Many studies have been conducted on this type of braced system to increase its energy dissipation (Bosco and Rossi, 2009; Mastrandrea and Piluso, 2009a, b).

In addition, various methods have been proposed by researchers and designers such as the knee bracing system, which is proposed by Aristizabal-Ochoa (1986). This system changes plastic deformation from simple yielding to plastic bending and therefore a much better performance in terms of hysteretic behaviour can be achieved. Different configurations of knee bracing system

Corresponding Author: Hassanali Mosalman Yazdi, Maybod Islamic Azad University, Iran Tel: +60173617694

are proposed by researcher to improve this system (Lotfollahi and Mofid, 2006; Mofid and Lotfollahi, 2006). However, considering the advantageous and limitations of these various braces in making openings, a special type of braced system is used in seismic areas, which is called Non-Geometric Brace (NGB) system. This braced system as shown in Fig. 1 consists of three members in which the third member connects the mid connection point of brace elements to the beam-to-column connection. A suitable plan of non-geometric brace can be used extensively to make more possibilities to have openings concurrent with its significant capabilities in energy dissipation.

Because of the cyclic nature of earthquake load, double bay rather than single bay of this system are used in seismic areas as shown in Fig. 2.

Many studies have been carried out regarding the seismic behaviour of this system under tensile brace elements (Moghaddam and Estekanchi, 1995, 1999). Evidences from recent earthquakes have shown that out-of-plane buckling of compressive brace element is more critical. In designing this system, the location of braced elements connection point, together with the members cross-section area and dimension of opening and frame have significant effect on the stiffness of the system. By considering these parameters, locating the best connection point which has the highest stiffness and lowest weight of brace elements is not trivial. Hence, designers mostly use trial and error method to determine the best arrangement of brace elements.

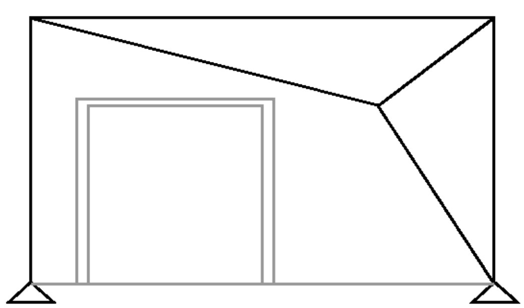

Fig. 1: A typical non geometric braced system

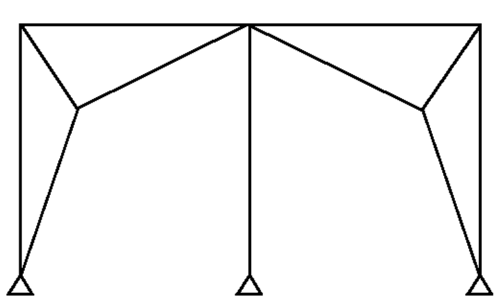

Fig. 2: A typical two bays NGB system

In this study, a method based on multi-objective genetic algorithm is proposed to help designers in the selection of the best connection point. The stiffness equation of the system is obtained along with the weight of brace elements. Both of these parametric formulas are presented as the fitness function. By modifying plain aggregate method, an option is proposed to help designers in prioritizing between the two fitness function through the introduction of significant coefficient. A MATLAB computer programme is used in order to do the calculations.

MODELING AND ANALYSIS

In order to model a non-geometric braced frame system, parameters m and n, which are the coefficients of width and height of the frame, respectively are introduced to express the location of connection point O as shown in Fig. 3. The frame is assumed as a truss system and analyzed as a statistically determinate pin jointed frame. Also, the axial deformation of brace elements is ignored.

With above definition, the geometrical parameters of this brace can be determined as follows:

$$L_1 = \sqrt{(nH)^2 + (L(1-m))^2} \tag{1}$$

$$L_2 = \sqrt{(mL)^2 + (H(1-n))^2} \tag{2}$$

$$L_3 = \sqrt{(nH)^2 + (mL)^2} \tag{3}$$

where, L_1, L_2 and L_3 are length of brace elements 1, 2 and 3, respectively.

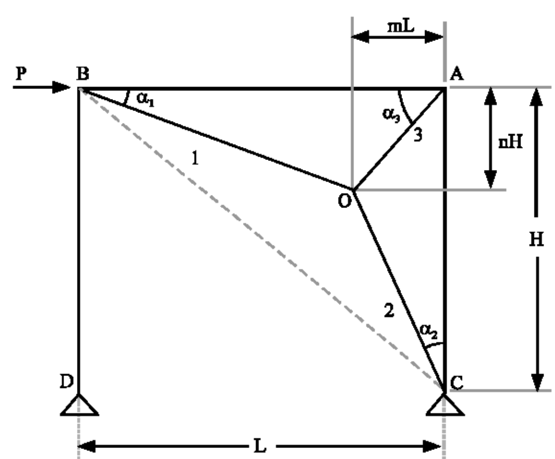

Fig. 3: A model of NGB frame

By solving equilibrium equations of statically determinate pin-jointed frame, axial forces of these brace members can be obtained as follows:

$$F_1 = \frac{-PH}{L\sin\alpha_1} \quad (4)$$

$$F_2 = \frac{-P}{\sin\alpha_2} \quad (5)$$

$$F_3 = \frac{-P}{\sin\alpha_3}\left(\frac{\cos\alpha_2}{\sin\alpha_2} - \frac{H}{L}\right) \quad (6)$$

DETERMINING THE WEIGHT AND STIFFNESS EQUATIONS

Generally, in designing all types of structures there are two important criteria which designers must consider i.e., as weight and stiffness of the structure. Most of the designers try to increase the system stiffness and simultaneously decrease the elements weight. The equations of these two parameters for a single frame NGB system are explained below:

Weight equation: It is acknowledged that location of the brace elements connection point has direct effect on the frame weight due to the length of the brace members. Therefore, based on the strength of materials principles, the relation between cross section areas of brace elements can be expressed by the proportion of brace member axial forces, therefore:

$$A_3 = \frac{A_1 L\sin\alpha_1}{H\sin\alpha_3}\left(\cot\alpha_2 - \frac{H}{L}\right) \quad (7)$$

$$A_2 = \frac{A_1 L\sin\alpha_1}{H\sin\alpha_2} \quad (8)$$

where, A_1, A_2 and A_3 are the cross-section area of elements 1, 2 and 3, respectively. Now, the total weight of the brace elements after simplification is:

$$W_T = \rho\sum_{i=1}^{3} A_i L_i = \rho A_1\left(L_1 + \frac{nL_2^2}{mL} + \frac{(1-(m+n))L_3}{mL_1}\right) \quad (9)$$

where, W_T is the total weight of the brace elements and ρ is the steel density. Consequently, this equation shows that the position of connection point which is introduced by the coefficients m and n has direct effect on the total steel weight.

Stiffness equation: The behavior of a structural system is significantly governed by its stiffness. In order to achieve the stiffness equation of the NGB system, the frame displacement is obtained by structural equation as follow:

$$\Delta = \sum_{i=1}^{3} \frac{P_i P_{i1} L_i}{E_i A_i} \quad (10)$$

where, i is the number of members, P_i is the axial force of member i due to lateral force P, P_{i1} is the axial force of member i due to unit lateral force, E_i and A_i are, respectively modulus of elasticity and cross section area of brace member i. In all computations, modulus of elasticity for all members is assumed constant and equal to E. Hence,

$$\Delta = \frac{PH^2L_1}{EA_1L^2\sin^2\alpha_1} + \frac{PL_2}{EA_2\sin^2\alpha_2} + \frac{PL_3(\cot\alpha_2 - \frac{H}{L})^2}{EA_3\sin^2\alpha_3} \quad (11)$$

By replacing Eq. 7 and 8 and trigonometric parameters of this frame (Fig. 3), Eq. 11 can be simplified as:

$$\Delta = \frac{P((nH)^2 + (L(1-m))^2)^{\frac{1}{2}}}{nL^2EA} \times \frac{((m-m^2)L^2 + (n-n^2)H^2)}{mn} \quad (12)$$

Based on Hooke's law, the stiffness of the system can be obtained as:

$$K = \frac{nL^2EA}{((nH)^2 + (L(1-m))^2)^{\frac{1}{2}}} \times \frac{mn}{((m-m^2)L^2 + (n-n^2)H^2)} \quad (13)$$

Parameters H, L, m, n, E and A can be varied to investigate the effect of changing the eccentricity of the diagonal members on the frame displacement and stiffness.

GENETIC ALGORITHM

Genetic Algorithms (GAs) are search and optimization tools, which work differently compared to classical search and optimization methods. This search technique is based on the principals of genetics and natural selection, initiated by Holland (1975). Because of their broad application, ease of use and global perspective, GAs have been increasingly applied to various search and optimization problems in the recent years (Kang and Kim, 2005; Aiello *et al*., 2006).

Genetic Algorithms (GAs) are initialized with a population of guesses. These are usually random and will be spread throughout the search space. Typically, these initial guesses are held as binary encodings of the true variables (Mitchell, 1996; Rothlauf, 2006). In the other word, encoding is the first operation in a GA. Each variable is represented by using a bit string which is merged to form a chromosome that represents a design. The elements of the string corresponds to genes and the values those genes can take to alleles. During each generation, each individual in the population is evaluated using the fitness function. Genetic operators are applied to the individuals of the population in order to generate the next generation of such individuals. The procedure continues until the termination condition is satisfied (Fonseca and Fleming, 1995; Coley, 1999). A typical algorithm then uses three operators i.e., selection, crossover and mutation to direct the population towards convergence at the global optimum.

The three main operators in the GAs can be explained as follows (Lawler, 1976; Goldberg, 1989; Michalewicz, 1999; Haupt and Haupt, 2004):

- Selection is the operator which selects chromosomes (individuals) in the population for reproduction. The fitter the chromosome, the more it is likely to be selected to produce. In the other word, a selection scheme determines the probability of an individual being selected for producing offspring by crossover and mutation. In order to search for increasingly better individuals, fitter individuals should have higher probabilities of being selected while unfit individuals should be detected only with small probabilities. Different selection schemes have different methods of calculating selection probability
- Crossover exchanges the chosen portions of two parents and generates the new individuals. These chosen portions are decided by the randomly chosen crossover points. One of the commonly used crossover operations is one-point crossover, which is also adopted in this study. As an example, the binary strings of 10000100 and 11111111 could be crossed over after the third locus in each string to produce the two off-springs of 10011111 and 11100100. The crossover operator roughly mimics biological recombination between two single chromosomes
- Mutation is a random alteration of a string that produces incremental changes in the offspring generated through crossover. By itself, mutation is equivalent to a random search. However, in GA, mutation also helps to prevent premature convergence

In this study, in order to substantially improve the search speed by not losing the best (or elite) member between the generations, another operator which is termed elitism is used. This operator will preserve the best individual of a population and consequently protect from failure of obtaining offspring in the following generation. To do so, they copy the best individual from the present population in the new one, normally achieving a speed increase in the obtaining of the optimal individual. Basically, elite individuals are exceptional in the mutation process.

ECCENTRICITY OPTIMIZATION BY GA

Pursuit to earlier explanation in determining the frame stiffness and weight of the elements can be considered that finding the best connection point which fulfil even only maximum stiffness or minimum steel brace element weight is not trivial. Currently, designers mostly use trial and error method to find the best connection point. In this study, an approach to locate the best connection point based on genetic algorithms is proposed. In order to limit the random generation of GA's individuals, a feasible area is introduced, which leads to faster convergence.

Feasible area: In this study, to decrease the iteration number of generations and to avoid unfeasible individuals to be in the population, a feasible area based on the dimensions of opening is introduced. There are many points located out of the opening in the panel area that has high stiffness along with lower weight of steel elements. But these points may not be a suitable location for connection point. In the other word, by using this location, it may lead to obstruction of opening by the brace elements. Thus, as shown in Fig. 4, a feasible area for the NGB frame is the common area between beam, column and the two lines that starts from the corner of the frame (point B and D) passing through the corner of the opening and ends at the beam and column (point M

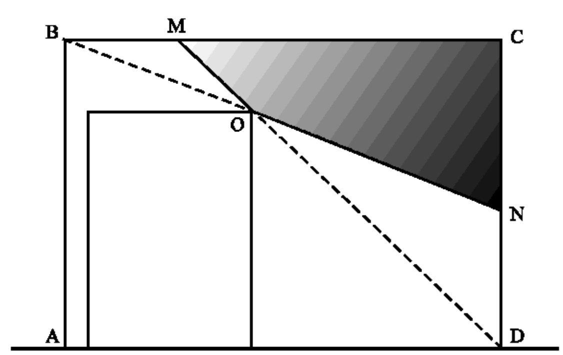

Fig. 4: Possible panel area for locating brace elements connection

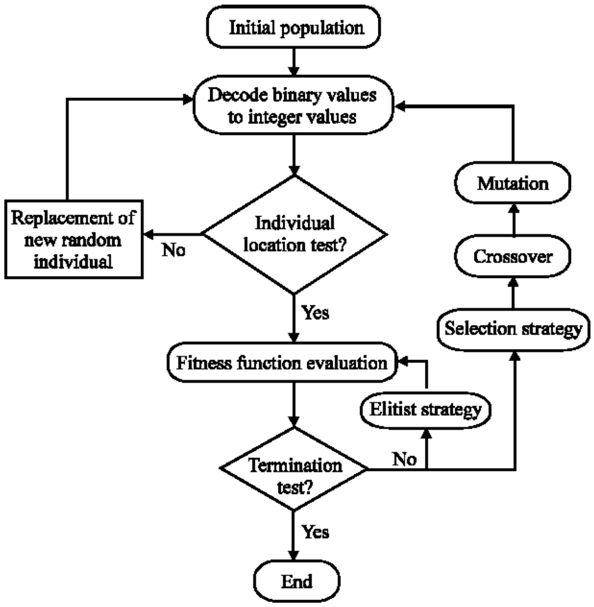

Fig. 5: A typical genetic algorithm with consideration feasible area

and N). Therefore, by determining this area which is hatched (Fig. 4) a good filtration can be performed and eventually preventing utilization of impossible individuals with respect to their location for better convergence, which lead to quick attainment of the best connection point.

Procedure in GA: Based on aforementioned subjects, a flowchart for finding the best connection point based on genetic algorithms is shown in Fig. 5. In this flowchart, the fitness function can be the stiffness equation if we consider stiffness as the main purpose of our optimization. On the other hand, if the main concept is minimizing the steel weight, the fitness function would be the weight formula. However, when designers need to consider both of these cases simultaneously, another approach is proposed.

Pursuit to earlier explanation regarding selection operator, the method which is used in this study for selection operation is rank-based selection. There are many different rank-based selection schemes. In this study, a rank-based selection scheme with a stronger selection pressure is used (Fonseca and Fleming, 1995; Sakawa, 2002; Haupt and Haupt, 2004).

Rank-based selection does not calculate selection probabilities from fitness values directly. Initially, it sorts all individuals according to their fitness values and then computes selection probabilities according to their ranks rather than their fitness values. Hence, rank-based selection can maintain a constant selection pressure in the evolutionary search and avoid some of the problems encountered by roulette wheel selection.

Now, based on the above explanation, the following tasks in the selection operator are carried out:

- Sorting cost function and their related individuals
- Determining the survival or keeping individuals number (N_{Keep}) as follow:

$$N_{Keep} = X_{rate} \times N_{Pop} \tag{14}$$

where, X_{rate} is the selection rate and N_{Pop} is the number of population.

- Going through selection of parents for pairing, based on rank weighting approach

In this approach, the probability related to each chromosomes of pairing pool is vice versa of its fitness value. In the other word, the chromosome with lowest cost has the highest probability for pairing (Michalewicz, 1999; Haupt and Haupt, 2004). Consequently, in this approach the probability of chromosome P_n is based on the chromosome's rank (n). Hence:

$$P_n = \frac{N_{Keep} - n + 1}{\sum_{n=1}^{N_{Keep}} n} \tag{15}$$

MULTI-OBJECTIVE OPTIMIZATION

Optimization of one fitness function was explained earlier based on GA. Here, an approach is developed in order to optimize the connection point's eccentricity, which leads to minimizing the steel brace elements weight along with maximizing the stiffness of the system.

Search problems encountered in the real world are often characterized by the fact that many objectives must be satisfied. Although, this topic is called multi-objective optimization, we are in fact dealing with the task of achieving acceptable values of a large number of objectives.

Conventional optimization techniques were not designed to cope with multiple-objectives search problems, which have to be transformed into single objective problems prior to optimization. On the other hand, evolutionary algorithms are considered to be better tailored to multiple-objectives optimization problems. This is mainly due to the fact that multiple individuals are sampled in parallel and the search for multiple solutions can be more effective. In brief, the multi-objective optimization is the area where evolutionary computation really distinguishes from its competitors (Sakawa, 2002; Zebulum *et al*., 2002). For instance, in this study there are two fitness functions, i.e., weight and system's stiffness. We are trying to obtain the best connection point that satisfies both of these function by having maximum stiffness and minimum weight.

However, evolutionary algorithms typically work with a scalar number to reward individuals' performance, i.e., the fitness value. In the case of a single-objective optimization problem, we call this scalar f(x), where x is a particular individual. Considering a multiple-objective problem, we can now define the fitness vector f(x):

$$f(x) = (f_1(x), f_2(x), \ldots, f_n(x)) \quad (16)$$

where, $f_i(x)$ represent the scalar components of f(x). The search problem is now restarted to the one of seeking for optimal values for all the functions $f_i(x)$.

Now, plain aggregation approach which is one of the evolutionary computing techniques is adopted in this study and is explained below.

Plain aggregation approaches: Plain aggregation approach is the easiest and most straightforward approach to transform the objective vector in a scalar. It is simply accomplished by the traditional weighted sum, i.e.,

$$f(x) = \sum_{i=1}^{n} w_i f_i(x) \quad (17)$$

Where:
$\sum_{i=1}^{k} w_i = 1$

According to the above equation, the fitness value of the individual x will be given by the sum, over n objectives, of the fitness corresponding to each objective, $f_i(x)$, multiplied by the weight w_i.

As the objective functions are usually of different magnitudes, the weights often need to be normalized. Thereby the above formula can be converted to (Zebulum *et al*., 2002):

$$f(x) = \sum_{i=1}^{n} w_i fn_i(x) \quad (18)$$

where, fn_i accounts for the normalized value of the fitness associated to the objective i, which attempts to compensate the fact that different objectives may have different natures and thus magnitudes. As a way to equalize the contribution of each objective in the fitness expression, the normalized fitness value in the following way is computed:

$$fn_i = \frac{f_i}{\bar{f}_i} \quad (19)$$

where, the denominator, $\bar{f}_i$, represents the average of the fitness values scored by the individuals with respect to function i. This formulation tried to avoid disproportionate contributions of the objectives in the aggregating of fitness equations.

The relative value of weights generally reflects the relative importance of each objective. Since, the method is specially effective when the relative importance of the objectives is known or can be estimated. The designer may vary the weights to reflect his preferences before solving the problem.

According to the above equation, the fitness value of the individual *x* will be given by the sum over n objectives (in this study n is equal to two), of the fitness corresponding to each objective, $f_i(x)$ multiplied by the weight w_i.

In preventing some practical problems in using this method and extending the decision of designer, a significant coefficient, α is applied to the above equation with a range from 0 to 1. This coefficient allows the designer to make a priority between stiffness and weight. In general, designers try so that their design have highest amount of stiffness along with minimum steel weight. But in some cases designers decide to select a connection point which has more stiffness although this selection increases the steel weight. Therefore, by introducing this coefficient, designer has the ability to determine the proportion of each fitness function in the normalize fitness function. Hence:

$$f(x) = \alpha w_1 f_1(x) + (1-\alpha) w_2 f_2(x) \quad (20)$$

where, $f_1(x)$ and $f_2(x)$ are the functions of stiffness and weight, respectively. Consequently, in order to determine the connection point Eq. 14 is used as the fitness function.

RESULTS AND DISCUSSION

The effect of eccentricity i.e., the location of connection point O from the diagonal member BC (Fig. 3) is investigated here. By using Eq. 13, a computer programme based on MATLAB was developed in order to examine the effects of parameters mentioned earlier.

For a particular height/span ratio (H/L = 4/4) and by setting n values, as shown in Fig. 6, the relationship of stiffness with increasing value of m is observed. The curves show that the stiffness increases as the values of m increases (i.e., point O moves closer to diagonal BC). The same effect can be seen when m is constant and n increases. The results are consistent with the findings by Moghaddam and Estekanchi (1995), which emphasize on the effect of eccentricity on the system's stiffness with tensile diagonal strut. Hence, we can conclude that with increasing eccentricity and getting connection point position close to the frame's corner, the stiffness of the system decreases.

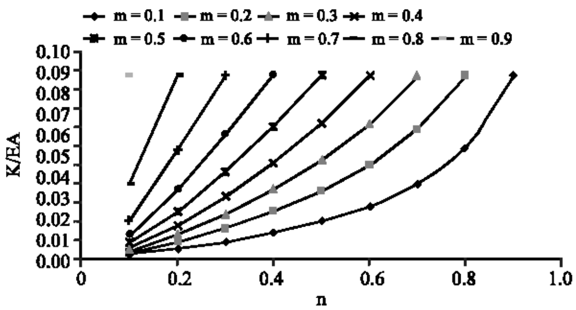

Fig. 6: Stiffness variation in NGB system (H/L=4/4)

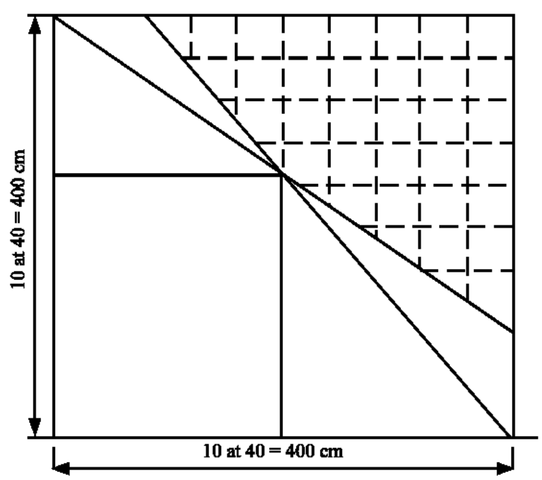

Fig. 7: Configuration of possible point to be a connection location

Genetic algorithm results comparison: In order to investigate the proposed approach based on multi-objective genetic algorithm, a similar frame adopted before is investigated. For this frame, an opening with height to width ratio of 2.5/2 is considered. All points shown in Fig. 7 are the possible brace element connection points for this frame configuration. All these points are determined based on different values of m and n in the feasible area. The system stiffness and brace elements weight of all these possible connection points located in the feasible area are calculated based on Eq. 9 and 13. Their values are shown in Table 1 as a coefficient of EA and Aρ, respectively, where, A is the cross section of element 1 (Fig. 3).

By using the proposed approach based on genetic algorithm and considering different population size, mutation rate, number of bits for each variable and selection rate, the results show a very good convergence and high precision on the determination of the connection point. The best connection point is located at the coordinate of X and Y equal to 1.9922 and 1.5058 m, respectively. Which this point refers roughly to m = 0.5 and n = 0.375. At this point, equal significant coefficient i.e., $\alpha = 0.5$ are considered for both objective functions. The stiffness and weight are found equal to 0.058017EA and 6.2048A t, respectively.

In another example, a frame with H/L ratio of 3/4 m and opening dimension of 2×2 m is considered. The stiffness and brace elements weight of all possible connection points are shown in Table 2 as a coefficient of EA and Aρ, respectively.

The connection point obtained by the proposed method, with significant coefficient equal to 0.5 for both of fitness functions is X = 1.9843 and Y = 1.0078 m. At this point, the stiffness and weight of the steel brace members are 0.066162EA and 5.3736A, respectively. By comparing the data of Table 2 with the result of this proposed method, it can be concluded that the determined point,

Table 1: System's stiffness and steel weight of brace members at different locations in the feasible area (H/L = 4/4)

		m						
n	Fitness function	0.1	0.2	0.3	0.4	0.5	0.6	0.7
0.1	Stiffness (×EA)	0.0015338	0.0024807	0.0035355	0.0049818	0.0072102	0.011024	0.014061
	Weight (×Aρ)	7.9511	6.2017	5.6569	5.4252	5.3344	5.3358	5.3676
0.2	Stiffness (×EA)	0.0043386	0.0075792	0.011137	0.015811	0.022646	0.03354	
	Weight (×Aρ)	10.8465	7.7611	6.7765	6.3246	6.0908	5.9628	
0.3	Stiffness (×EA)	0.0079057	0.014235	0.021103	0.029814	0.041943		
	Weight (×Aρ)	12.6491	8.661	7.3532	6.7082	6.3111		
0.4	Stiffness (×EA)	0.012307	0.022361	0.033076	0.046225			
	Weight (×Aρ)	13.4026	8.9443	7.4421	6.6564			
0.5	Stiffness (×EA)	0.017855	0.032317	0.047384				
	Weight (×Aρ)	13.2095	8.692	7.1299				
0.6	Stiffness (×EA)	0.025214	0.045					
	Weight (×Aρ)	12.2034	8					

Shaded area is out of the feasible area

Table 2: System's stiffness and steel weight of brace members at different locations in the feasible area (H/L = 3/4)

		m					
n	Fitness function	0.1	0.2	0.3	0.4	0.5	0.6
0.1	Stiffness (×EA)	0.00197	0.00295	0.00409	0.00569	0.00822	0.012682
	Weight (×Aρ)	6.2284	5.2426	4.936	4.806	4.7568	4.7608
0.2	Stiffness (×EA)	0.00609	0.00983	0.01397	0.0196	0.0228171	0.04256
	Weight (×Aρ)	7.8912	6.143	5.5874	5.3358	5.2106	5.1498
0.3	Stiffness (×EA)	0.011653	0.01947	0.02798	0.03922	0.05572	
	Weight (×Aρ)	8.9738	6.6934	5.9502	5.5887	5.3712	
0.4	Stiffness (×EA)	0.018739	0.03174	0.04567	0.06360		
	Weight (×Aρ)	9.4868	6.9054	6.0401	5.5902		
0.5	Stiffness (×EA)	0.027795	0.04706				
	Weight (×Aρ)	9.4615	6.8051				
0.6	Stiffness (×EA)	0.039752					
	Weight (×Aρ)	8.9443					

Shaded area is out of the feasible area

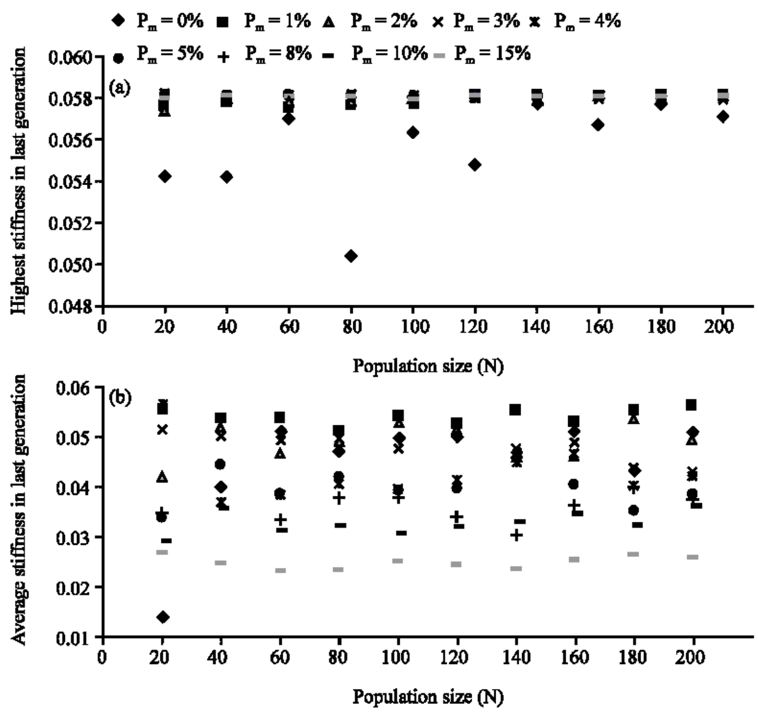

Fig. 8: Effect of mutation rate on fitness value as stiffness, (a) highest stiffness and (b) average stiffness (H/L = 4/4)

with m = 0.5 and n = 0.33, could be the best choice for the connection point.

Evidently, this method gives very accurate results compared to the conventional trial and error method. It can be concluded that the optimization based on multi objective genetic algorithm program is reliable due to accuracy and efficiency of this method and the results can be guaranteed as the best selection point.

Mutation rate: In order to investigate the effect of mutation rate on the optimization of the connection point, a frame configuration similar to the first example is adopted. Two cases are examined i.e. single objective and multi-objective. In the first case, the fitness function is solely the stiffness of the system with selection rate equal to 0.5. The average stiffness for different population size (N) with various mutation rate is shown in Fig. 8.

As shown in Fig. 8a, by imposing different mutation rate, the highest stiffness value with different value of population size (N) is approximately identical for different mutation rate, except for mutation rate equal to zero. In addition, by increasing mutation rate, the mean of stiffness decreases. For mutation rates less than 4 percent, approximately similar average stiffness is obtained (Fig. 8b).

In the second case, the effects of mutation rate in the multi-objective algorithm are studied. To investigate this matter and compare with the first case, significant

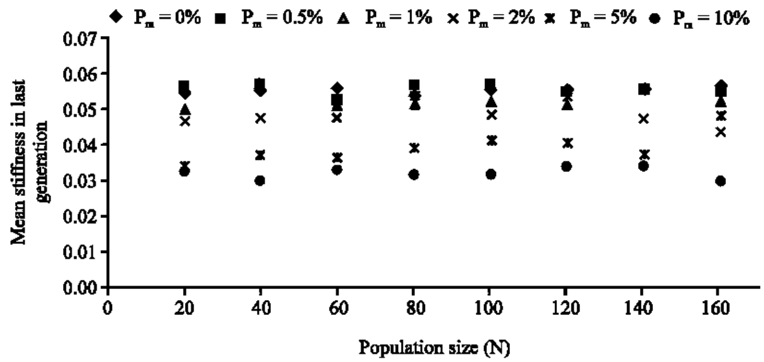

Fig. 9: Mean of fitness value with consideration of stiffness as the fitness function

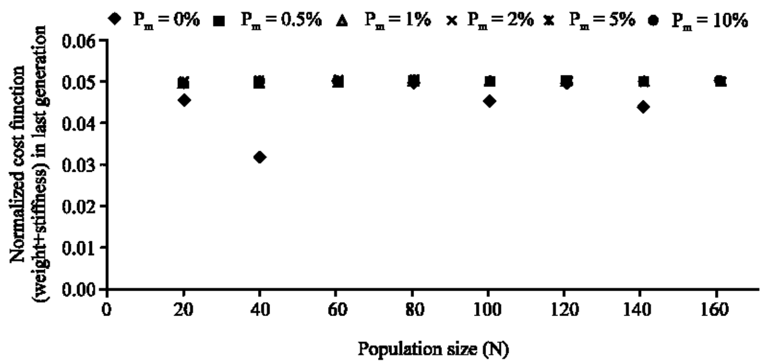

Fig. 10: Mean of normalized fitness value with consideration of stiffness and steel weight as the fitness function

coefficient for stiffness is considered 100%. The results shown in Fig. 9 give similar output compared to Fig. 8. The results of the mean normalized of multi objective fitness values by using the same significant coefficient (i.e., equal to 50%) for both fitness functions illustrate the same results. However, because of normalization, their variations are not sensitive except for mutation rate equal to zero as shown in Fig. 10, which is due to premature convergence, Therefore, the mutation operator is essential to keep the diversity and renew the genetic material.

Overall it can be concluded that when mutation rate increases, the stiffness average decreases due to increase of distances between individuals. However, if the mutation rate is too low, the GA performance degrades. On the other hand, if it is too high, the evolutionary process will approach a random search. Although, the best mutation rates are problem dependent, for this case a value between 1 to 4% is recommended. In this range, the probability of random search decreases and also in lower number of individual and iteration, results with good accuracy can be obtained and eventually takes lesser time. Earlier studies regarding the mutation possibility (Fonseca and Fleming, 1995; Kang and Kim, 2005) recommended a range between 0.01 to 4%. However, this study indicates that the results with mutation possibility values of less than 1% will lead to instable condition. On the other when the values are more than 4%, the computation will be quite exhaustive as more random search and more iteration are required.

Consequently, if an evolutionary algorithm is developed based solely on selection and crossover without mutation rate, the system converges too soon. In the other word, the program terminates in primary generation and it could not search the best selection in more extended panel area. Hence, the results will not be trustful.

Elitist individual: As mentioned before, in preserving the best individual in each generation and preventing from missing in the next generation, the best individual with maximum stiffness is selected as an elite individual and directly transferred to the next generation (Gero *et al*., 2005; Rothlauf, 2006). To highlight the importance of elite individuals, a frame with earlier configuration is adopted. The selection rate is 0.5 and the fitness function is only the stiffness of system. The mean of stiffness for different individual population is shown in Fig. 11a and b for different mutation rates of p_m = 3 and 5%. Results indicate

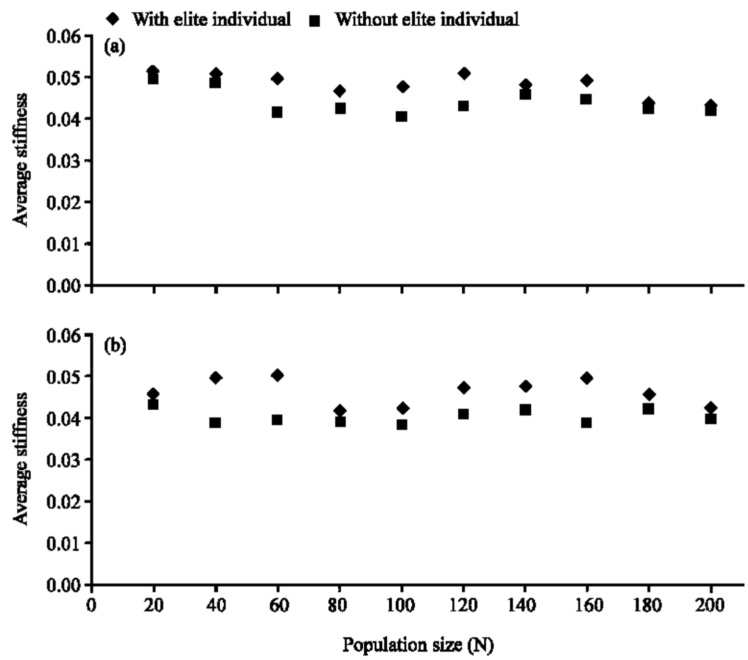

Fig. 11: Effect of elite individuals on the stiffness of generations for single objective function, (a) mutation rate = 3%, and (b) mutation rate = 5%

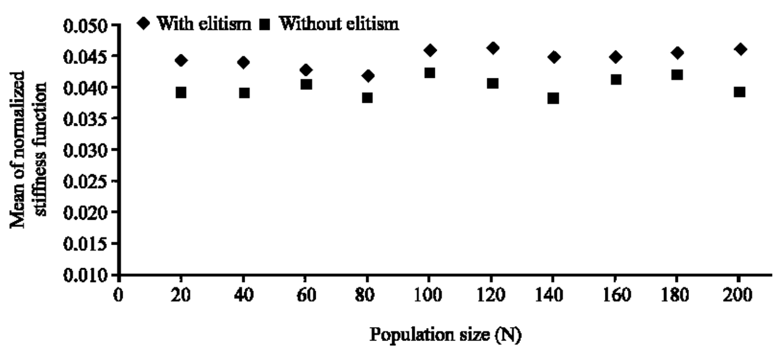

Fig. 12: Effect of elite individuals on the normalized fitness value for multi objective genetic algorithm (mutation rate = 3%)

that the average stiffness of generation without considering the role of elite individuals is lower than the case with elite individual, which indicates the dispersions between individuals of a generation is more than generations with elite individual. This conclusion supports the finding from previous studies regarding the effect of elitism strategy (Gero *et al*., 2005), which is used in GA to obtain results in lower number of iteration. The same results can be obtained in the multi objective fitness function as shown in Fig. 12 for 3% mutation rate.

CONCLUSION

Non-geometric braced system is commonly used in seismic areas because of the possibility for making openings. The connection location of the brace elements has significant role on the stiffness and behaviour of the system in resisting seismic loads. In this study, it is found that by increasing eccentricity and moving connection point closer to the beam to column connection, the stiffness of the system decreases. However, finding the best connection point with highest stiffness and lowest steel weight considering various parameters related to opening dimensions, members geometric property and etc., is not trivial. In this study, a parametric equation for stiffness is computed and multi-objective genetic algorithms approach is proposed to determine the brace element connection point. In order to guide designers in locating the connection point with limitation related to opening, a significant coefficient is proposed in this approach. In this method, a modification is done on the proportion of stiffness fitness value in comparison to weight fitness value. Thereby, with this method, a designer can obtain the connection point faster and with higher accuracy. In order to increase the convergence in genetic algorithm, a feasible area is introduced to avoid improper individuals. In addition, this study has shown that the best mutation rate is between 1 to 4% and by using elitism operator, accurate results with faster convergence can be achieved.

REFERENCES

Aiello, G., M. Enea and G. Galante, 2006. A multi-objective approach to facility layout problem by genetic search algorithm and electre method. Robotics Comput. Integrated Manuf., 22: 447-455.

Aristizabal-Ochoa, J.D., 1986. Disposable knee bracing: Improvement in seismic design of steel frames. J. Struct. Eng., 112: 1544-1552.

Bosco, M. and P.P. Rossi, 2009. Seismic behaviour of eccentrically braced frames. Eng. Struct., 31: 664-674.

Coley, D.A., 1999. An Introduction to Genetic Algorithms for Scientists and Engineers. 1st Edn., World Scientific Press, Singapore.

Fonseca, C.M. and P.J. Fleming, 1995. An overview of evolutionary algorithms in multiobjective optimization. Evolutionary Computation, 3: 1-16.

Gero, M.B.P., A.B. García and J.J. del Coz Díazb, 2005. A modified elitist genetic algorithm applied to the design optimization of complex steel structures. J. Construct. Steel Res., 61: 265-280.

Goldberg, D., 1989. Genetic Algorithms in Search Optimization and Machine Learning. Addison Wesley Publishing Co., Reading, Massachutes.

Haupt, R.L. and S.E. Haupt, 2004. Practical Genetic Algorithms. 2nd Edn., John Wiley and Sons, New Jersey, ISBN: 0471455652.

Holland, J.H., 1975. Adaptation in Natural and Artificial Systems. 1st Edn., University of Michigan Press, Michigan, Ann, Arbor, ISBN: 0472084607.

Kang, J.H. and C.G. Kim, 2005. Minimum-weight design of compressively loaded composite plates and stiffened panels for postbuckling strength by genetic algorithm. Comp. Struct., 69: 239-246.

Lawler, E.L., 1976. Combinatorial Optimization: Networks and Matroids. Holt, Rinehart and Winston, New York.

Lotfollahi, M. and M. Mofid, 2006. On the design of new ductile knee bracing. J. Construct. Steel Res., 62: 282-294.

Mastrandrea, L. and V. Piluso, 2009a. Plastic design of eccentrically braced frames, I: Moment-shear interaction. J. Construct. Steel Res., 65: 1007-1014.

Mastrandrea, L. and V. Piluso, 2009b. Plastic design of eccentrically braced frames, II: Failure mode control. J. Construct. Steel Res., 65: 1015-1028.

Michalewicz, Z., 1996. Genetic Algorithms+Data Structures: Evolution Programs. 1st Edn., Springer, Verlag, Berlin.

Mitchell, M., 1996. An Introduction to Genetic Algorithms. 1st Edn., Massachusetts Institute of Technology, A Bradford Book, Cambridge, Boston, ISBN: 0262133164.

Mofid, M. and M. Lotfollahi, 2006. On the characteristics of new ductile knee bracing systems. J. Construct. Steel Res., 62: 271-281.

Moghaddam, H., I. Hajirasouliha and A. Dosstan, 2005. Optimum seismic design of concentrically braced steel frames: Concepts and design procedures. J. Construct. Steel Res., 61: 151-166.

Moghaddam, H.A. and H. Estekanchi, 1995. On the characteristics of an off-centre bracing system. J. Construct. Steel Res., 35: 361-376.

Moghaddam, H.A. and H.E. Estekanchi, 1999. Seismic behaviour of offcentre bracing systems. J. Construct. Steel Res., 51: 177-196.

Rothlauf, F., 2006. Representations for Genetic and Evolutionary Algorithms. 2nd Edn., Springer Verlag, New York.

Sakawa, M., 2002. Genetic Algorithms and Fuzzy Multi-Objective Optimization. 1st Edn., Kluwer Academic Publisher, Boston, ISBN: 0-7923-7452-5.

Zebulum, R.S., M.A.C. Pacheco and M.M.B.R. Vellasco, 2002. Evolutionary Electronics: Automatic Design of Electronic Circuit and Systems by Genetic Algorithms. 1st Edn., sCRC Press, UK.