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On the Genetic Algorithm Optimization of Non-Geometric Brace Systems

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Abstract

One of the desirable brace systems in seismic areas can be presented as non-geometric brace system, which has the advantage of architectural transparency. This system consists of three members. The non-straight diagonal members (which introduce eccentricity to the brace system) are connected to the corner of the frame by a third member. The connection's location on these three-brace elements has a significant role on the stiffness of this system. Although designer can compute the stiffness of the frame based on structural analysis principals, but finding the best connection's location offering the highest stiffness value in the panel area with various parameters is indeed intricate. In this paper, eccentricity optimization to obtain the connection point which has the highest stiffness is carried out based on genetic algorithm. In addition, the effect of using elite individual, selection rate, number of mutation and crossover on the number on generation and iteration are investigated. This study highlights that the utilization of elite individual has significant effect on decreasing the number of generation for optimizing the eccentricity of this bracing system.

Keywords

Brace, Genetic Algorithm, Earthquake, Optimization.

1. Introduction

Concentric and eccentric brace frames are two common methods for designing buildings to resist lateral loads. Concentric braced systems are more desirable because of the relative good stiffness, along with the ease of construction and economy aspects; hence resulting the adoption of this group more common than eccentrically braced frames (IF et al., 1988). Eccentric braces need more construction accuracy thereby it decreases construction speed and imposes higher cost in spite of better stiffness performance and higher energy dissipation. This is because they mainly yield in bending and, therefore their hysteresis behaviour is close to ideal elastic-plastic systems without significant deterioration of strength and stiffness (Engelhardt and Popov, 1989). However, these systems has disadvantageous and drawbacks under severe earthquakes. Therefore desingners try to develop various expedients and innovations to either increase the ductility and the capacity for energy dissipation, or reduce stiffness by using base isolation system such as knee bracing systems. This system has more advantageous because it changes plastic deformation from simple yielding to plastic bending, and therefore a much better performance in terms of hysteresis behaviour can be achieved (Balendra et al., 1990).

In relation to aformentioned methods there is a particular configuration of brace elements which is so called Non-Geometric Braced (NGB) System. This invented system is more desirable in seismic areas because of its capability in dissipating seismic loads and moreover, its great opportunity in making openings in the panel areas. This brace system as illustrated in Figure 1, consists of three elements, where the diagonal members are not straight but have an eccentricity, connected to the corner of the frame by a third member. This system allows architects to have more opening in the panels.

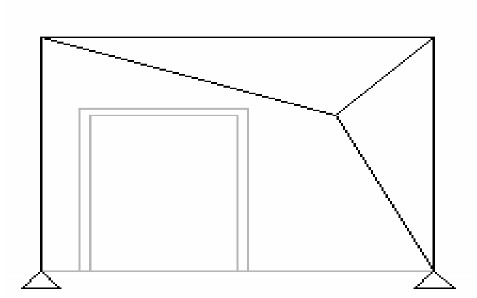

Figure 1. A typical non-geometric brace system

In order to examine the influence of the brace elements' connection position and stiffness of the system, analytical studies have been developed. In spite of the possibility in calculating stiffness for a defined connection point of this particular frame, finding the best connection point in a panel area with highest stiffness value under several constraints, such as cross-section area of brace members, dimensions of openings, models of elasticity and distances of selected point from the frame corner is not trivial. In general, investigations and computations of stiffness for different points in a panel area with such miscellaneous and different variables are sometimes impossible for designers. Therefore, in this paper an attempt is made to determine the best connection point by using genetic algorithm to help designers in their designs.

2. Modeling and Equations

By considering truss system in plane frame and assumed negligible axial deformation due to the axial forces , a simple model of this system is shown in Figure 2. The brace elements are connected at point O. The location of point O, which is away from the straight diagonal member BC, will introduce eccentricity, e to the system. The dimension of the members can be defined by two parameters m and n , which are the coefficients of the span and height of the frame, respectively.

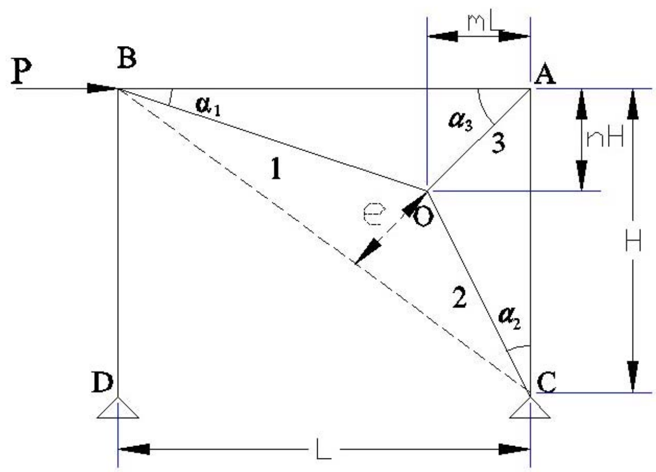

Figure 2. A model of NGB frame

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

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

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

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

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

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

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

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

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

In above equations α_1 , α_2 , and α_3 are the angles between the brace elements 1, 2 and 3 to the beam and the columns of the frame, meanwhile the frame lateral displacement is computed as follows:

$$\Delta = \sum_{i=1}^{3} \frac{P_i P_{i1} L_i}{E_i A_i} \quad (7)$$

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 the modulus of elasticity and the cross section area of brace member i , respectively. In this analysis it is assumed that axial deformation of the beam and columns are negligible. In all computations, modulus of elasticity of all members is assumed constant and equal to E.

Hence, lateral displacement can be represented as:

$$\Delta = \frac{PH^2 L_1}{EA_1 L^2 Sin^2\alpha_1} + \frac{PL_2}{EA_2 Sin^2\alpha_2} + \frac{PL_3 (Cot\alpha_2 - \frac{H}{L})^2}{EA_3 Sin^2\alpha_3} \quad (8)$$

Logical assumption which is based on principles of strength of materials is that the cross section areas of brace elements must be proportioned to the axial forces. Therefore, by replacing them in Equation 8, and considering Hooke's law, the stiffness of the frame, K is given as:

$$K = \frac{nL^2 EA}{((nH)^2 + (L(1-m))^2)^{\frac{1}{2}}} \times \frac{mn}{((m-m^2)L^2 + (n-n^2)H^2)} \quad (9)$$

The parameters H , L , m , n , E and A are varied to investigate the effect of changing the eccentricity of the diagonal members on the frame displacement and stiffness.

3. Parametric Studies

The effect of eccentricity i.e. location of connection at point O from the diagonal member BC (distance e in Figure 2) are investigated here. By using the derived equations, a computer program based on MATLAB was developed in order to examine the effects of parameters mentioned above on the frame stiffness.
For a particular height to span ratio (e.g. H/L=4/4) and different values for n, the relationship of stiffness with increasing value of m can be obtained, as shown in Figure 3. 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.

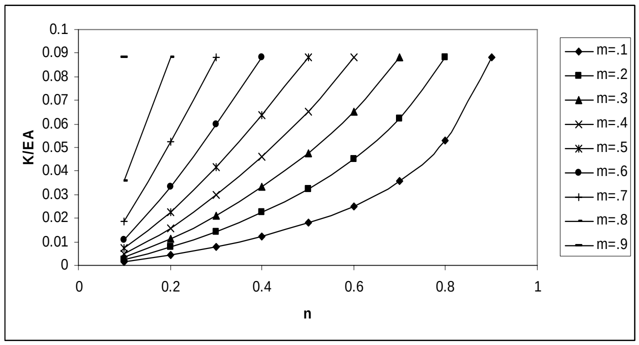

Figure 3. Effect of connection point on the stiffness of NGB frame (H/L=4*/4)*

4. Genetic Algorithm Fundamentals

Genetic Algorithms (GA) are search and optimization algorithms that are based on the Darwinian theory of evolution. The underlying concept is that the existence of all living things is based on the rule of "survival of the fittest". Darwin also postulated that new breeds or classes of living things come into existence through the processes of reproduction, crossover and mutation among existing operations. The GA processes population of chromosomes (individuals), successively replacing one such population with another. The chromosomes in a GA typically take the forms of bit string. Each chromosome can be considered as a point in the search space of candidate solutions. The GA most often requires a fitness functions that signs a score (fitness) to each chromosome in the current population.
Genetic algorithms start with an initial population of individuals or chromosomes generated at random. The individuals evolve though successive iterations, called generations. During each generation, each individual in the population is evaluated using the fitness function. Genetic operators, generally biologically based, 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. On the other hand, after selection, crossover and mutation have been applied to the initial population, a new population will be formed and the generational counter is increased by one. This process of selection, crossover and mutation is continued until a fixed number of generations have elapsed or some form of convergence criterion has been met (Balendra et al., 1990; Coley, 1999; Rothlauf, 2006). The simplest form of genetic algorithms involves three types of operators: selection, crossover (single point) and mutation (Chambers, 1995; Mitchell, 1996). These terms can be explained as follows:

i) Selection – In this operator, individuals in the population are chosen for reproduction according to their fitness values. Selection determines which individuals are chosen for mating and how many offspring each selected individual produces.

ii) Crossover - this operator randomly chooses a locus and exchanges ‘tails’ between two chromosomes to create two off-springs. For example, the binary strings 10000100 and 11111111 could be crossed over after the third locus in each to produce the two off-springs 10011111 and 11100100. The crossover operator roughly mimics biological recombination between two single chromosome organisms (see Figure 4).

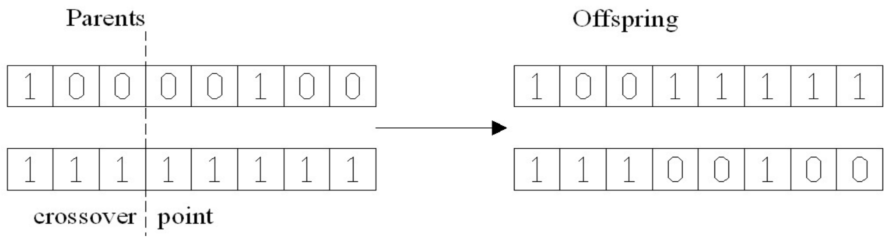

Figure 4. Single point crossover operation.

iii) Mutation - this operator randomly flips some of the bits in a (binary) chromosome. For example, the string 00000100 might be mutated in its second position to yield 00100100 (see Figure 5).

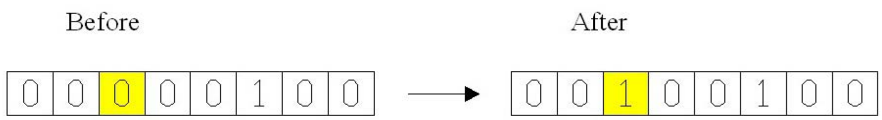

Figure 5. Mutation operation.

Continuous development of genetic algorithms has led to the obtaining of so-called elitist genetic algorithm, the aim of which is to avoid the best individual of a population failing to obtain offspring within 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 (Geroa et al., 2005).

5. Determination of Braced Elements’ Connection Point by GA

Equation 9 indicates that the stiffness of the non geometric brace system depends on the eccentricity of the braced elements connection which is defined by two variables as m and n. Therefore, knowing the opening dimensions and cross section areas of the elements, a structural designer has to go through a trial and error method to find a good location for the connection point. Moreover, the suggested connection location cannot be proved as the best selection. In this section, by considering the characteristics of evolutionary algorithms, GA is used to help designers to find the best location for the connection point. Hence, at first it is necessary to restrict populations' individuals to be in feasible panel area which will be explained later.

5.1 Boundary Conditions of Individuals

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. Although there are many points located out of the opening in the panel area that has high stiffness, it is necessary to investigate the location of these points to ensure the construction of diagonal members not interrupted by the opening. Thus, the feasible area for the braced elements is the common area between beam, columns 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 and N) as illustrated in Figure 6. Therefore, by determining this area (which is hatched in Figure 6) a good filtration can be performed and eventually preventing utilization of impossible individuals with respect to their location for better convergence.

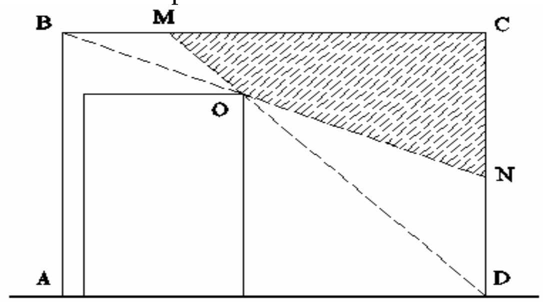

Figure 6. Possible panel area for locating brace elements' connection point

5.2 GA Flowchart Explanations

As mentioned before, in finding the best connection point a MATLAB program adopting genetic algorithm is developed which is presented in the flowchart as shown in Figure 7. In addition to the outline of typical genetic algorithm which was explained before, some additional stages and explanations regarding finding the best connection point can be presented as follows:

-Investigate the random individual population position: in this stage all random individuals which is located out of the feasible area will be replaced by new individuals until all of them located in this area.

-Selection: at this stage, all sorted individuals with consideration of the selection rate value will be maintained or terminated. In general, the individuals with low probability will be replaced with the offspring of the mated survived individuals. For the individuals with higher stiffness, they have more probability to have better offspring, hence the parents are selected for mating by the probability of their weight. Meanwhile the individual with highest stiffness value is kept as the elite individual to avoid missing the good selections in each generation and reserve it for the next generation.

-Crossover and Mutation: Single point crossove and mutation change the genes of chromosomes, consequently some of individuals which had been generated by these operators may be located out of the feasible area, therefore its necessary to ensure that the location of the new individual be in the feasible area.

Whenever the termination criteria are fulfilled, the program instantly terminates and the individual with maximum stiffness is stored as the best selection for connection point.

6. Results and Discussions

In this section, the GA's results will be compared with trial and error method, followed by investigations on effective parameters in GA. In the other word, the accuracy of results obtained from GA program is compared against the computation based on Equation 9. As an example, a frame with height to span ratio of 4/4 and the opening dimensions with height to width ratio of 2.5/2 is adopted as shown in Figure 8. The coefficient of m and n is given as follows:
m and $n = 0.1, 0.2, ..., 0.9$.

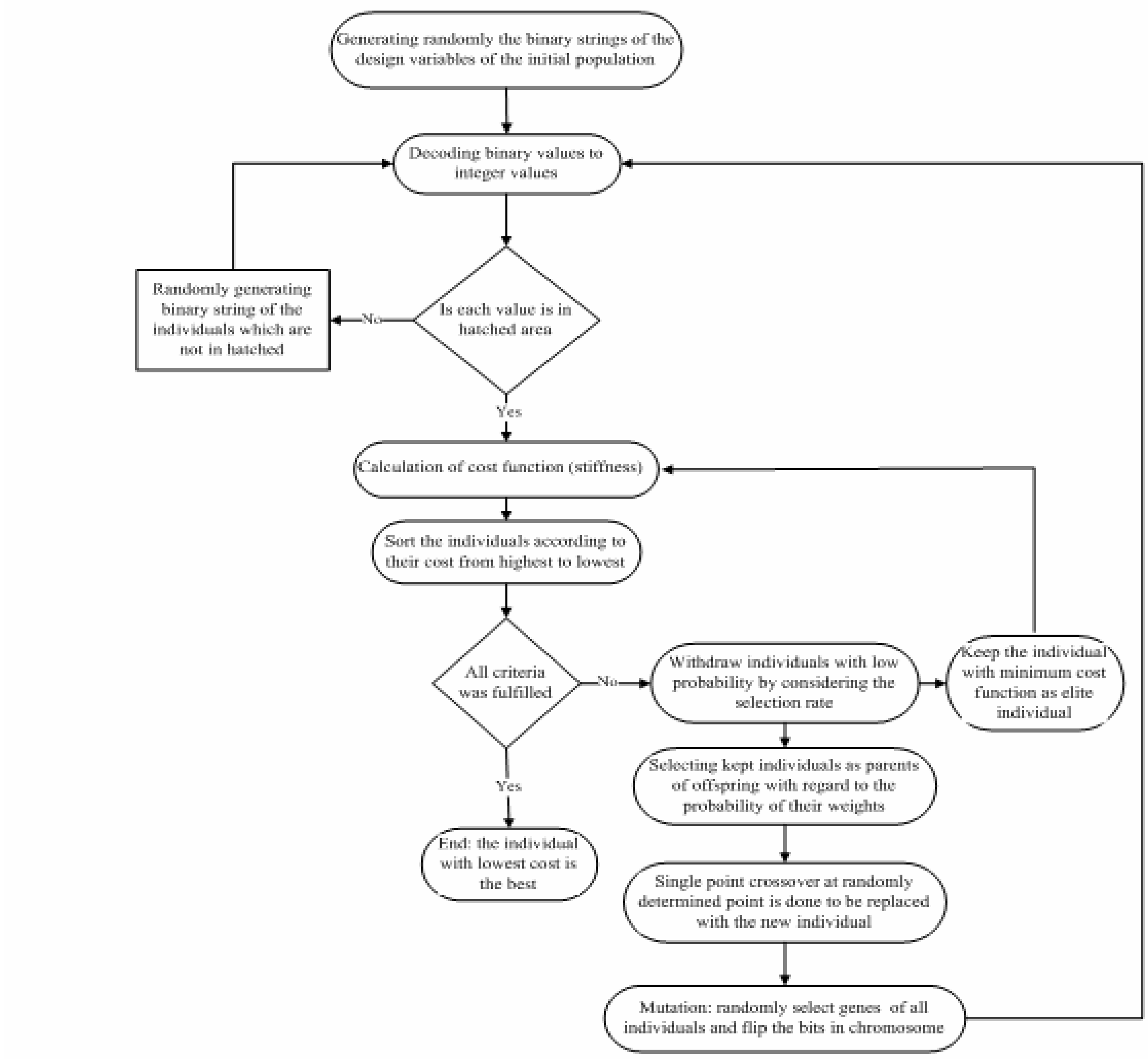

Figure 7. Flowchart of Genetic Algorithm for finding the best connection point of braced elements

By using Equation 9, the frame stiffness with different values of m and n are calculated and shown in Figure 8 as a coefficient of K/EA. For this particular configuration, the results indicate that the stiffness of the best selection for the connection point is equal to 0.0581EA, which is located in a point with a distance of X=2 and Y=1.5 meter from top right corner of the frame.

By using the same frame configuration, a program based on genetic algorithm considering different population size, mutation rate, number of bits for each variable and selection rate is examined. In all cases, the results show a very good convergence and high precision where it is found that the connection point is at the coordinate of X and Y equal to 1.9994 and 1.5004 meter respectively. At this point, the stiffness is 0.058059EA, which gives very good accuracy. It can be concluded that the optimization based on GA program is reliable due to accuracy and efficiency of this method.

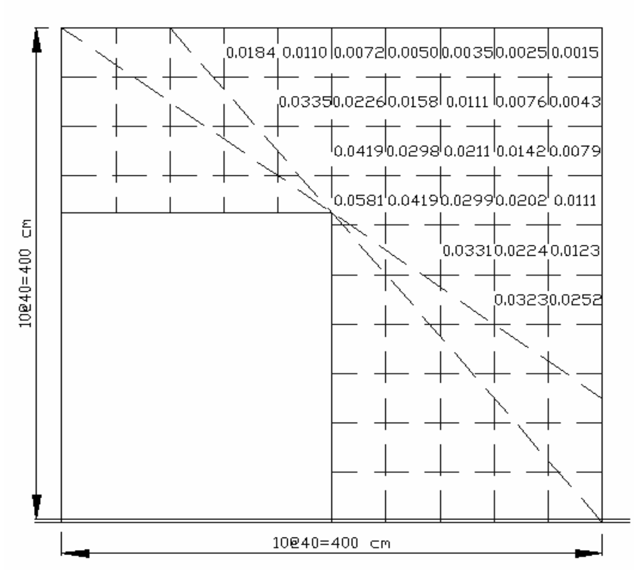

Figure 8. Feasible connection points of a NGB System(H/L=4/4)

7. Conclusion

Non geometric brace system which is used in seismic areas is a good system for resisting seismic load. At the same time, it allows greater possibility for architects to have more opening. However, finding the best location for the brace elements' connection point by considering various parameters such as cross section area of brace members, opening dimension and other factors is quite complicated and time consuming for designers. Here, a new method based on Genetic Algorithm is proposed to find the best point for the brace element connection. The results indicate that finding the brace elements' connection point with this new method is very reliable and accurate compared to time consuming trial and error method. By using mutation operator and introducing a boundary condition for individuals, the individuals can be controlled within the feasible area, thereby decreasing the number of iterations and ultimately improving the computational time.

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