REPAIRED CHROMOSOME IN GENETIC ALGORITHM FOR STEEL STRUCTURE OPTIMIZATION

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ABSTRACT

A new optimization procedure for designing a steel frame structure is presented in this paper. A repaired or "modified" chromosome in genetic algorithm is intoduced in the optimization procedure. The proposed method is applied to two stuctural models. The first model is a three storey ordinary steel structure moment frame designed according to AISC-ASD, while the second one is a three storey eccentrically steel braced frame designed according to AISC-LRFD. From the analysis carried out, it is concluded that the optimization process of using repaired chromosome in the genetic algorithms results a better solution than an ordinary genetic algorithms. The new proposed method is more stable, reliable and faster in computing process; furthermore, it gives a lighter or less structural weight.

Keywords: chromosome, genetic algorithm, optimization, steel structure

1. INTRODUCTION

A final objective of an application of the genetic algorithms (GA) is an automated and optimized design procedurefor frame steel structures. An excellentmethod which combining a commercial Finite Element Method (FEM) program with the GA in parallel computing method has alreday been developed (Ghozi, et al, 2011). In addition, a chromosome repaired process may due incorporated with the GA method above and gave a better performance and solution (Michalewich, 2006). That is why, it will be a fruitfull procedure to find out how it works for solving steel structure optimization problem. Since the advantage of commercial FEM programs, like SAP 2000, are already well known for structural design purpose. It will be a good idea if the comercial program is combined wih GA procedure for solving the design optimization of steel structures. Furthermore, the repaired chromosome technique is implemented in the GA process itself. For this reason, the difference between ordinary GA optimization result with and without chromosome repaired process will be discused later.

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2. THEORY

2.1.Structural Member Arrangement Concept

Usually, most designers use the concept that the lower storey structural member should be stronger than the upper storey structural member. For example, the stronger columns in the lower storey are bigger than the upper storey for its cross sectional area, height, depth, elastic modulus, plastic modulus or radius of gyration. Since the concept of strong column weak beam is applied, then column arrangement concept for the columns, from bottom to upper level, based on column height and cross sectional area. It is considered to arrange the upper level columns have higher in heght as well as the cross sectional area. This concept is then deployed to choose WF profile for columns, beams and braces for multistorey steel structures in design procedure. Usually, the optimization methods pursue the best profile configuration of structure; however, the mehod does not consider the above mentioned problem. The fitness method in the optimization procedure can't differentiate between one structure with a failure in the bottom column and the other structure with a failure in the upper level column. So it is necessary to make an important constraint, such as the strong column weak beam concept, so that the fail of thebottom columns are avoided.

2.2. Chromosome Repairing (CR)

Chromosome repairing (CR) is one strategy to change chromosome to be feasible in getting a better solution in the optimization procedure (Michalewich, 2006). With chromosome repairing method,an original unfeasible chromosome is replaced by a new feasible chromosome. In this paper, CR is deployed by GA method. So, there are two GA in the optimization prcedure, one is a big GA for steel structure optimization process and the other one ia a little GA for CR process. Only chromosome with random value under 0.005 will be repaired (see Figure 1).

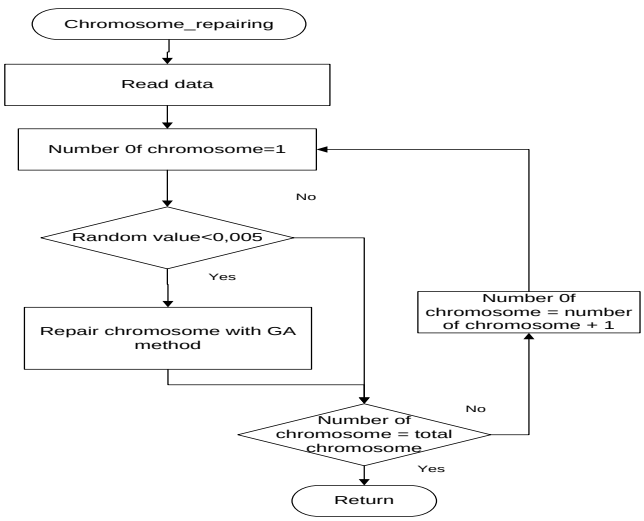

Figure 1: Flowchart of chromosome repairing.

Chromosomes are repaired with objective functions to minimize weight subjected to constraint of weight, joint connection and column height.With CR procedure, the result structure will have four characteristics: 1) having smallest value of weight, 2) columns in upper storey has smaller height than in lower storey, 3) at every beam-column connection joint, beam's width is smaller than column's width, and 4) columns in upper storey has smaller cross sectional area than in lower storey.

2.3.Combination of GA, CR and SAP2000

Genetic Algorithm (GA) optimization procedures in this paper are processed in parallel computing method. Optimization problems are already done in previous study using combination of GA and SAP2000 (Ghozi, et al, 2011). Then further study is done here in order to add Chromosome Reparing in GA combined with SAP2000 (see Figure 2).

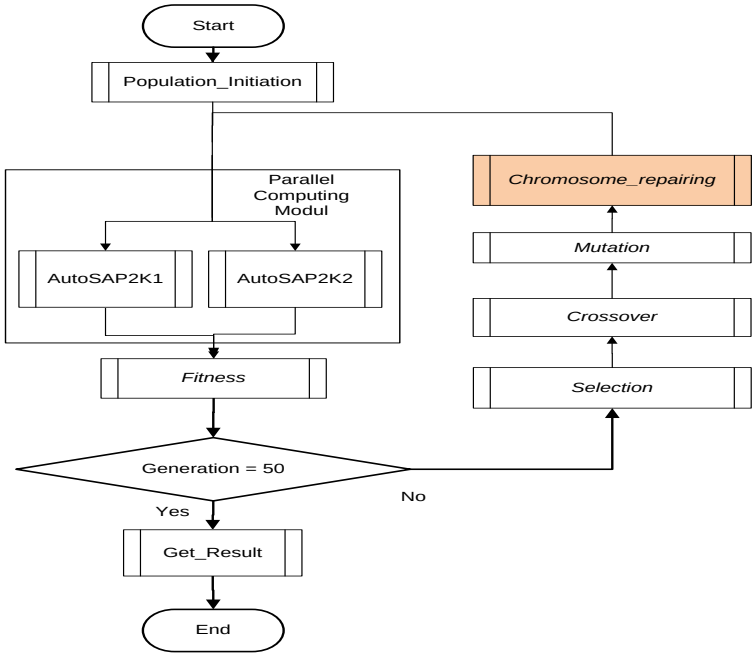

Figure 2: Flowchart of GACR-SAP2000.

3. EXAMPLES

The first example of structure models is designed according to the AISC–ASD specification (see Figure 3). A displacement constraint was imposed as: interstorey drift <storey height × (0.015/Cd), where Cd is taken as 4. Modulus of elasticity of E = 200 GPa (29 × 10^3 ksi), a yield stress of Fy = 248.2 MPa (36 ksi) and a material unit weight of g = 76.8 kN/m3 (2.83 × 10^{-4} kip/in3) were used. The frame is considered to be under dead, live, snow and earthquake loads (see Safari, 2011 for details).

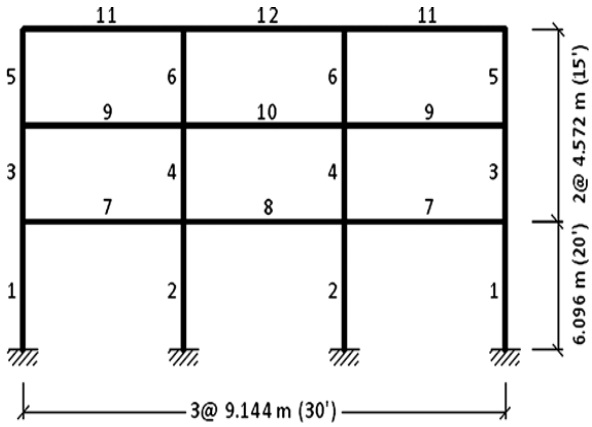

Figure 3: The first structure model (Safari, 2011).

About 269 types of WF profiles used as available profiles are taken from SAP2000 database. Two method's resultsare compared in this paper. The first method is to minimize the weight of structure using simple GA method and the second is using GACR (Genetic Algorithms combined with Chromosome Reparing method) process. Both methods have same objective function.The objective function is to minimize the weight subject to four constraints (stress, drift, connection joint,and column's height constraint):

$$Objfunc = (\sum \rho_i A_i L_i) \text{ x } \left(1 + (4 - cp) \sum Stress_i + \sum drift_{story} + \sum BC_{bcj} + \sum CD_{ccj}\right) \qquad (1)$$

Where *i* is element number, *Objfunc* is objective function, ρ is unit weight, A is of cross section, L is element length, cp is column position constraint, $Stress_i$ is stress constraint, $drift_{story}$ is displacement constraint, and JC_{bcj} is joint connection constraint and CD_{ccj} is column height constraint.

For stress constraints, the capacity ratio of each element is limited to equation (H1-1 AISC-ASD):

$$ratio = \left(\frac{f_a}{F_a} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}}\right) \leq 1 \qquad \text{if} \quad \frac{f_a}{F_a} < 0{,}15 \qquad (2)$$

And:

$$ratio = \left(\frac{f_a}{F_a} + \left(\frac{C_{mx} f_{bx}}{\left(1 - \frac{f_a}{F'_{ex}}\right) F_{bx}} + \frac{C_{my} f_{by}}{\left(1 - \frac{f_a}{F'_{ey}}\right) F_{by}}\right)\right) \leq 1 \quad \text{if} \quad \frac{f_a}{F_a} > 0.15 \qquad (3)$$

Where f_a is calculated axial stress, F_a is allowable axial stress, $f_{bx,\,by}$ is calculated bending stress at major and minor axis, respectively, $F_{bx,\,by}$ is allowable bending stress at major and minor axis, respectively, F'_{ex}, F'_{ey} = Euler stress devided by safety factor $^{23}/_{12}$, and C_{mx} , C_{my} is reduction factor.

For practical purposes, the height of column section in the upper storey must be less than that in the lower storey. Also, the flange width of the beam at is not allowed to be larger than that of the column, it can be expressed as:

$$\frac{b_{fb}}{b_{fc}} < 1 \qquad \text{and} \qquad \frac{d_{c,top}}{d_{c,bottom}} < 1 \tag{4}$$

where, b_{fb}, b_{fc} , $d_{c,top}$ and $d_{c,bottom}$ denote the flange width of beam, the flange width of column, the depth of the column section above and below each storey floor, respectively.

The second example of the structure to be optimized shown in Figure 4, which is designed according to AISC-LRFD. Displacement constraint in the interstorey drift is limited to 0.0025 times the storey height. The structure model is divided into 15 elements (Bruneau, et all, 1998).

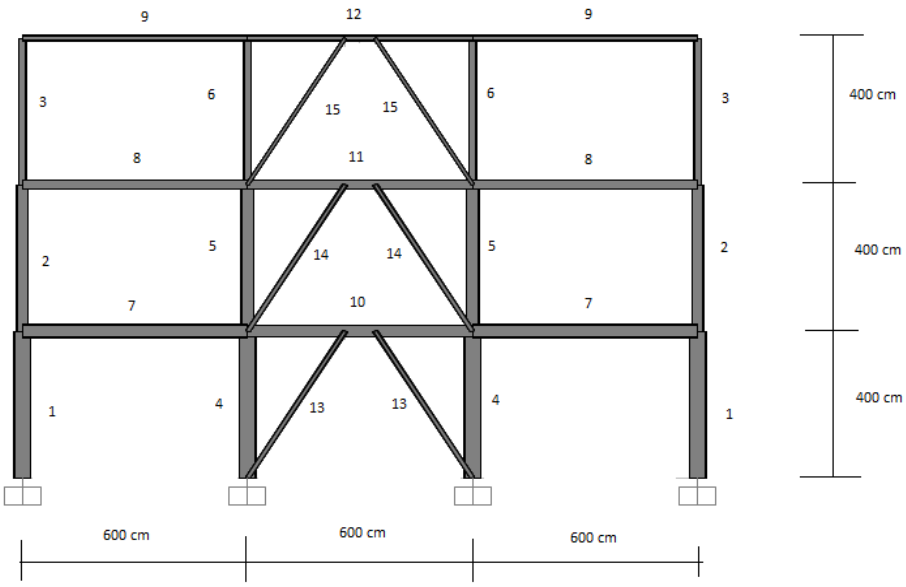

Figure 4: The second structure model (Joni, 2012).

ASTM A572 Grade 50 steel with a specified yield strenght of 345 Mpa (50 ksi) is used for the beams, columns, and links. ASTM A500 Grade B square structural tube manufactured to a specified yield stength of 320 Mpa (46 ksi) is used for the eccentric braces.

The Structure is subjected to loads such as: gravity live loads, dead loads and earthquake load. (see Joni, 2012 for details). The earthquake load is calculated according to IBC 2006 with reduction factor*(R)*= 8, *System overstrength* (Ω) = 2, *Deflection amplification (Cd)* = 4, Importance factor*(I)* = 1 and *Site Class*= D. The 266 types of WF profile used for the beams and column, and 332 types of HSS profiles used as available brace profiles, and all od them are taken from SAP2000 database. The objective function is to minimize the weight of structure subjected to three constraints : stress, displacement, and configuration of the profile properties. The objective function can be expressed as follows:

$$Objfunc = \min \quad (\sum \rho_i A_i L_i)\, x\big(1 + (4 - cp) \sum Stress_i + \sum drift_{story} + \sum BC_{bcj} + \sum CD_{ccj} + \sum BB_{bbr}\big) \tag{5}$$

Where:

i is element number, *Objfunc* isobjective function, ρ is unit weight, A is area of cross section, L is length of element, *cp* is column position constraint, $Stress_i$ is stress constraint, $drift_{story}$ is displacement constraint, and JC_{bcj} is beam/column width ratio constraint, CD_{ccj} is column's depth constraint and BB_{bbr} is brace/beam width ratio constraint.

For stress constraints, the capacity ratio of each element is limited to equation (H1-1 AISC-LRFD) :

$$\frac{Pu}{\varphi Pn} + \frac{8}{9}\left\{\frac{Mu33}{\varphi bMn33} + \frac{Mu22}{\varphi bMn22}\right\} \qquad \text{if } {}^{Pu}/_{\varphi Pn} \geq 0.2 \tag{6}$$

And :

$$\frac{Pu}{2\varphi Pn} + \left\{\frac{Mu33}{\varphi bMn33} + \frac{Mu22}{\varphi bMn22}\right\} \qquad \text{If } {}^{Pu}/_{\varphi Pn} < 0.2 \tag{7}$$

Where Pu is ultimate axial force, Pn is nominal axial force, $Mu33, Mu22$ is ultimate moment force at major and minor axis, respectively, $Mn33, Mn22$ is nominal moment force at at major and minor axis, respectively (AISC, 2005).

All GACR procedures are carried out with the parameters: 50 populations, 50 generations, 0.8 crossover, mutation 0.005, crosses a cut point, the elitism of 25% and use the rest of the roulette wheel selection. The models are optimized with GACR 30 times because of natural stochastic behavior of GA method. Every optimization process results 50 data and an average structure weight value will be calculated from data in the same generation and then plotted to one graph. This procedure produces one graph line and will be compared with data from GA's result. For the best result of GACR, data are taken from one chromosome with the highest fitness value.

4. RESULTS AND DISCUSSION

Comparison of best GACR's result and GA's are shown in Table 1. The first structure model GACR results 96.08 kN or 75.94% of the ordinary GA result. For the second structure model GACR results 4757.24 kG or 69.95 % of the ordinary GA results. While Figure 5 shows plotting of the structure weight of GA as weel as GACR process. GACR plots shorter and faster than GA's (see Figure 5). Comparing to ordinary GA procedure, for obtaining the optimum weight of 119.20 kN for the first structure model using GACR needs only 79% numbers of generation and saves 5.70% computing time. In addition, for the second structure model in obtaining the optimum weight of 6800.67 kG, the GACR procedure needs only 17.67% number of generation and saves 71.58% computing time. Both results are shown in Figure 6.

Table 1: Result of GACR and GA process

Group	First Structure Model		Second Structure Model	
	GA (Safari, 2011)	The best of GACR	GA (Joni, 2012)	The best of GACR
Generation	50 generation	50 generation	300 generation	50 generation
1	W14 x 53	W14 x 48	W18x55	W18X40
2	W14 x61	W21 x 73	W18x55	W18X35
3	W14 x48	W14 x 48	W18x46	W10X30
4	W14 x39	W14 x 43	W18x55	W18X50
5	W14 x48	W10 x 39	W18x50	W16X31
6	W14 x33	W12 x 30	W18x35	W10X30
7	W21 x 50	W21 x 44	W16x26	W16X26
8	W21 x 50	W21 x 44	W16x26	W16X26
9	W18 x 50	W21 x 44	W16x26	W8X21
10	W21 x 44	W21 x 44	W18x46	W10X19
11	W18 x 50	W21 x 44	W16x40	W10X17
12	W21 x 44	W21 x 44	W5x19	W4X13
13	---	---	HSS12x6x250	HSS7X4X.1875
14	---	---	HSS12x6x250	HSS4X3X.250
15	---	---	HSS5x5x1875	HSS3-1/2X2-1/2X.250
Weight	119.20 kN	96.08 kN	6800.67 kG	4757.24 kG

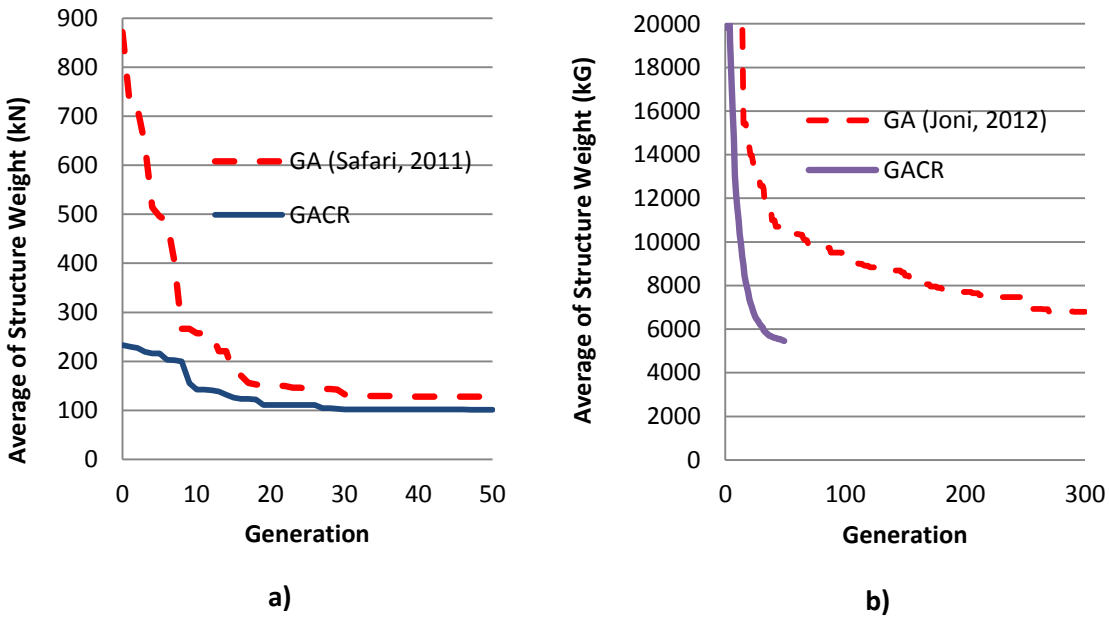

Figure 5: Plot of average structure weight: a) First Structure, b) Second structure

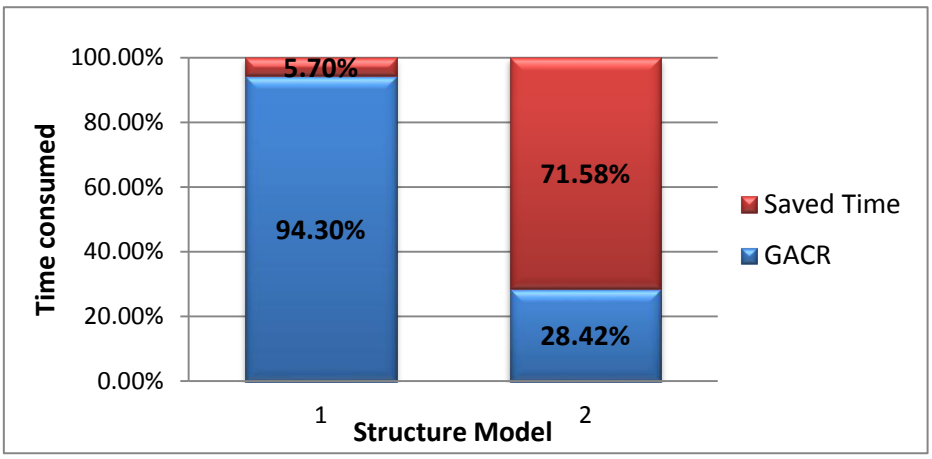

Figure 6: The time computing consumed

5. CONCLUSION

The optimization process with GACR has already been applied to the two structure models. The first model is the three storey ordinary steel structure moment resisting frame designed according to AISC-ASD, while the second one is the three storey eccentrically steel braced frame designed according to AISC-LRFD. The optimization using GACR method results weight 24.06% for first structure model and 30.05% for second structure model less than GA's. The proposed method saves 5.70% and 71.58% computation time than GA's for the first and second structure models, respectively. It is concluded that the GACR method is more reliable and faster in computing process; furthermore, it gives a lighter or less structural weight.

REFERENCES

American Institute of Steel Construction., (2005).“Specification for Structural Steel Buildings”. Chicago: AISC, Inc.

American Institute of Steel Construction (1989).“Manual of steel construction-allowable stress design”. Chicago. 1989.

International Code Council, Inc. (2006).“International building code”. Illinois.

Bruneau, M., Uang, C. M., and Whittaker, A., (1998).“Ductile Design of Steel Structures”. New York: McGraw-Hill.

Ghozi, M., Aji, P., and Suprobo, P., (2011). “Evolutionary Parallel Sap2000 for Truss Structure Optimization”, International Journal of Academic Research. Vol. 3, No. 2, Part IV:1140-1145.

Goldberg, D.E., (1989). Evolutionary Algorithm in Search, Optimization and Machine Learning. Addition wesley publishing company Inc, USA,.

Joni, R., (2012). “Optimization and Reliability Assessment of Eccentrically Braced Frame (EBF) Steel Structures”. Surabaya: Civil Engineering Department FTSP-ITS.

Michalewicz, Z. (2006)," Genetic Algorithms + Data Structures = Evolution Programs, 3rd edition". Charlotte : Springer, 2006.

Safari, D., Maheri M.R., and Maheri, A. (2011) Optimum design of steel frames using a multiple-deme GA with improved reproduction operators, Journal of Constructional Steel Research, 67 (2011) 1232–1243.