EFFECTS OF STRONG COLUMN WEAK BEAM RATIO AS CONSTRAINT FOR STEEL FRAME OPTIMIZATION

By Mohammad Ghozi

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ABSTRACT

An approach is presented as usage of genetic algorithm (GA) concept for steel frame optimization. The purpose of this paper is to discuss differences between result of optimization with and without strong column weak beam concept for optimizing steel frame structure. The optimization processes are carried out through 660 members of 2D steel structure model using GA-SAP2000. With strong column weak beam ratio as constraint in optimization, it is not easier to raise the fitness value but the structure will have smaller total drift and good arranged column's plastic modulus. It is concluded that strong column weak beam constraint is important and should be used in structural design.

Keywords: Genetic algorithm, Optimization, Steel structure, SAP2000, Strong column weak beam.

INTRODUCTION

AISC Seismic has arranged ratio of flexural strength to make structures have "strong column weak beam" behaviour. With this limitation columns always have stronger flexural strength than beams at every joint. At this stage flexural strength is defined as plastic moment (AISC, 1999).

The application of genetic and evolutionary computation to the automated design of structures has followed several avenues. The first is topology and shape optimization, in which the applications have included elastic truss structures subjected to static loading (Cai & Thiereut, 1993). There have also been research efforts devoted to developing algorithms for optimized structure topologies to satisfy user-determined natural frequencies. The second major area of automated design using genetic algorithms has been their application for optimal member sizing for truss structures using linear elastic analysis with U.S. design specifications (Adeli & Sarma, 2006).

The final major application of genetic algorithms (GA) has been the automated design of steel frame structures. One excellent method was combining commercial finite element method (FEM) program with iteration method to find required area of steel reinforced concrete plate (Khennane, 2007) and commercial FEM program with GA in parallel computing method (Ghozi, et al, 2011).

Since we know the advantage of commercial FEM program for analyze and design structure and its combination with GA, it will be good for academics for using combination of commercial FEM-GA-Parallel computing for research in optimization. For this reason, it will be discussed the difference beetwen optimization result with and without "strong column weak beam"constraint.

THEORIES

Strong column weak beam concept

The current design methodology in the AISC Seismic Provisions (AISC, 2002) requires that the specified interstory drift of a steel moment frame be accommodated through a combination of elastic and inelastic frame deformations. The inelastic deformations are provided through development of plastic hinges at pre-determined locations within the frame. When moment connections are used, the plastic hinges are developed through inelastic flexural deformations in the connecting beams and in the column panel zone. This results in a strong column and weak beam design philosophy (AISC, 1999). This code requires that the sum of column flexure strengths at a joint should be more than the sum of beam flexure strengths (AISC SEISMIC 1, 9.6).

Sap2000

SAP2000 structure analysis program is a well known finite element analysis tool which already used for analyzing and modeling structure. SAP2000 could process or import the file input with extension MDB, XLS, TXT and SDB. SAP2000 also could export analysis result and design to files with extension XLS, TXT and SDB. After input file being opened, SAP2000 will run analysis, save result and design all members (CSI, 2000a,b). From the output file, we can get required data such as frame stress and joint displacements as indicators for acceptance criteria (Ghozi, et al, 2011).

Simple Genetic Algorithm

GA, a member of Evolutionary Algorithm (EA), is a population-based global search technique based on the Darwinian theory (Goldberg, 1989). Common operators used in GA are initialization of population, evaluate population, selection, mating, crossover, mutation, stopping criteria and get results (Gen & Cheng, 1997). The preliminary approach of GAs is Simple Genetic Algorithm (SGA). SGA guides the evolutionary search by a single population *Pi*. The size of *Pi* is denoted by *SP*. Individuals are encoded in a string scheme associated with one of the codes of the binary, integer, and real. In the evolutionary search, the promising individuals $Pi-sel$ and $Pi+1-sel$ are chosen from the population by a selection operation (roulette wheel, stochastic universal sampling, ranking, truncation, etc.). Then, the individuals chosen are applied to recombination and mutation operation (one point or multipoint crossover and mutation, uniform crossover, etc.). These evolutionary operations (mutation mut, crossover *cr*, and selection *sel*) are governed by their related evolutionary parameters *Par* (mutation and recombination probability rates, selection pressure, etc.). The population *Pnew* evolved by the application of these evolutionary operators is decoded. Then, the fitness values are computed by use of this population. The evolutionary search is executed to transmit (migration) the individuals (emigrant and immigrants) to the next populations until satisfying a predetermined stopping criteria (Gen & Cheng, 1997; Haupt, 2003).

Master-slave concept for GA

As a matter of influence the GA robustness, many researchers develop methods for fastening GA runtime. One of famous method used for parallel GA is distributed optimization for GA (Lampinen, et al, 1999).

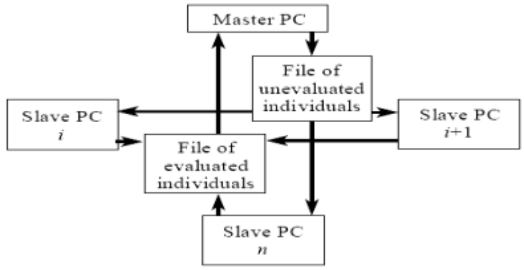


Figure 1. Parallel GA for distributed optimization (Lampinen, et al, 1999).

GA procedures are processed in Master PC and Slave PC's take only the remaining SAP2000's processes. In this method numbers of PC are used as Slave PC's (see Figure 1). Numbers method of hardware configuration for parallel computing definitively decrease required running time. We can use expensive and robust tool as supercomputer or use cheap PCs as a group of slaves. Boewulf method will be chosen because this method use cheap PCs.

Figure 2. Flowchart a) in slave PC b) in Master PC (Ghozi, et al, 2011).

From master PC, the input file send to each slave PC. After send input files, master PC send message to each slave. The message is to command slave PC to 1) run SAP2000, 2) analyze input file, 3) design the input file (if necessary), 3) close SAP2000.

ISSN: 2223-9553
Volume 1, Issue 2, September 2011

Each input file must have one output file. If number of output files is equal to number of input files, each slave send all output files to master PC. After all output files have been sent, each slave send message to master PC. The message is to let master PC to evaluate and calculate fitness value of each output file (see Figure 3). Raw data for of drift calculation are taken from table : Joint Displacements, data for stress constraint calculation are taken from table : *Steel Design 1 – Summary Data AISC-LRFD99*. Raw data for strong column weak beam ratio are taken from table : Frame Section Properties 01 - General. This iteration is stopped when generation = 20.

STEEL STRUCTURE MODEL FOR OPTIMIZATION

Figure 3. 2D steel structure model (Adeli, 2006)

The structure to be optimimized is a 2D 36 stories steel structure (modified structure from Adeli, 2006). Each story has 11,68 ft height and each beam has 15 ft length. Twelve different types of columns are used in every three stories, twelve different types of beams are used in every three stories and twelve different types of braces are used in every three stories. 256 types of WF profiles used as available profiles are taken from SAP2000 database. Two objective functions compared in this paper. The first objective function is to minimize weight subject to three constraints (stress constraint, displacement constraint, flexural strength constraint) and forms as :

$$Objfunc1 = \sum \rho_i A_i L_i + +gen_g{}^2 \left(\sum re_i + \sum rj_j + \sum scwb_j\right) \quad (1)$$

And the second objective function is to minimize weight subject to two constraints (stress constraint and displacement constraint) and forms as :

$$Objfunc2 = \sum \rho_i A_i L_i + +gen_g{}^2 \left(\sum re_i + \sum rj_j \right) \quad (2)$$

Where *Objfunc* is objective function, ρ is unit weight, A is Area of cross sectional, L is length of element, gen is generation, re is element constraint, and rj is displacement constraint. $Re_i = 0$ if $ratio_i < 1$ and $re_i = ratio_i^2$ if $ratio_i > 1$, $rj_i = 0$ if $drift_i < 0,04672$ and $rj_i = drift_i^2$ if $drift_i > 0,04672$, $scwb_j = 0$ if $R_j < 1$ and $scwb_j = R_j{}^2$ if $scwb_j > 1$.
For displacement constraint, the interstory drift is limited to 0.004 times the story height. For stress constraints, the capacity ratio of each element is limited with equation (H1-1 AISC-LRFD99):

$$\text{ratio} = \frac{P_u}{\varphi P_n} + \frac{8}{9}\left\{\frac{M_{u33}}{\varphi b M_{n33}} + \frac{M_{u22}}{\varphi b M_{n22}}\right\} \text{ for } \frac{P_u}{\varphi P_n} \geq 0.2 \quad (3)$$

$$\text{ratio} = \frac{P_u}{2\varphi P_n} + \left\{\frac{M_{u33}}{\varphi b M_{n33}} + \frac{M_{u22}}{\varphi b M_{n22}}\right\} \text{ for } \frac{P_u}{\varphi P_n} < 0.2. \quad (4)$$

Where P_u is the required compressive strength, P_n is the nominal compressive strength, M_u is the required flexural strength, M_n is the nominal flexural strength, $\varphi = 0{:}85$ and $\varphi_b = 0{,}9$.
For the flexural strength constraint, the ratio of beam to column stiffness at every joint must under 1, with form as (9.6 AISC Seismic):

$$R = \frac{\Sigma_{n=1}^{nb} M_{pbn}}{\Sigma M_{pc}} < 1. \quad (5)$$

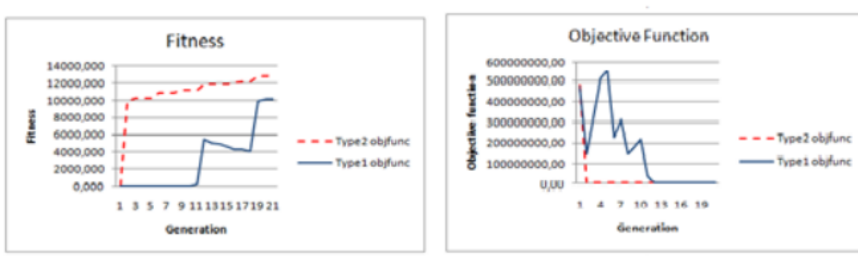
Where R is strong column weak beam ratio, M_{pbn} is plastic moment of beams, M_{pc} is plastic moment of columns above and below the joint.

The loading on the structure consists of a dead load of 375 lbs/ft' and a live load of 450 lbs/ft'. The lateral loads due to wind are computed according to the UBC (1994). Lateral forces are determined by assuming a basic wind speed of 113 km/h (70 mil/h), exposure C, and an importance factor of 1. Earthquake force is defined by auto lateral load according to UBC97 and with CQC modal combination of response spectrum, SRSS directional combination, modal analysis case use 8 modes Eigen vector type mode. GA process are carried out with parameters: 40 individuals, 20 generations, 0,8 crossover, 0,005 mutation, 1 cut point crossover, 25% elitism and the rest use roulette wheel selection.

RESULT AND DISCUSSION

Optimization of 2D brace has done successfully with the presence (type 1) and absence (type 2) of beam to column strength ratio as constraint. Objective function, total drift, maximum displacement and also fitness plots are taken from individual which has the highest fitness at each generation. Each fittest individual of every generation have already zero stress constraint violation. They are plotted as result of optimization process and are shown in figures below.

As we can see in Figure 4, fitness of type 2 raise in ease way than the type 1. This is caused by the number of constraints only two. Type 1 objective function structure has no violation since generation 14 as type 2 has it in generation 2.



a) b)

Figure 4. a)Fitness b) objective curve

The total drift and diplacement of structure are also analyzed. The structure is mostly accepted if it has small drift and bigger column's plastic modulus in lower story. Type 2 objective function have bigger total drift than type 1. This could happen because structure with type 1 objective function has stronger columns than beams and the lower columns have bigger plastic modulus than columns at upper story (see Figure 6). The type 1 objective function structure has good arranged column's plastic modulus.

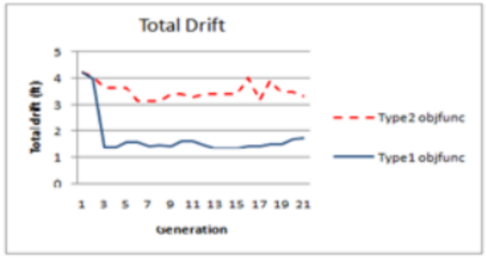


Figure 5. Total drift of structures.

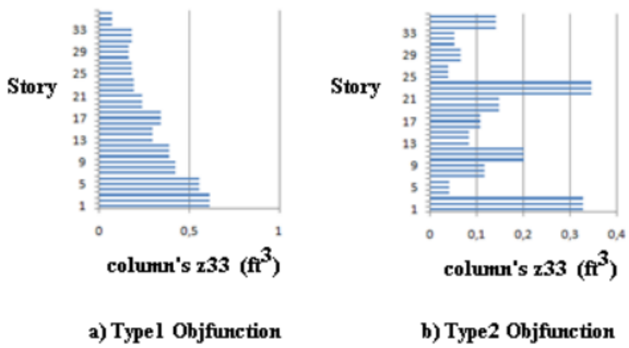


Figure 6. Column's plastic modulus from fittest individual at the last generation.

From the weigth of structure which are taken from the best individual at the last generation, it can be seen that type 2 of objective function have the lighter weight than type 1 at both structures (see Table 1 below).

Table 1. Weight structure from fittest individual at the last generation.

Items	Details	
Type of Objfunction	Type 1 objfunct	Type 2 objfunct
Weight	986745 lbs	773978 lbs

CONCLUSION

Two optimization process have been completed to compare effect of presence and absence of beam-column strength ratio. 2D steel structure with 660 elements has been optimized as model with combination of GA-SAP2000. The objective function is to minimize weight subject to three and two constraints. Structure with beam-column strength ratio as constraint is more difficult to raise the fitness value, has smaller total drift of structures and has good arranged column's plastic modulus but bigger in weight. It is concluded strong column weak beam as constraint is useful and should be included in design of steel structure.

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ISSN: 2223-9553
Volume 1, Issue 2, September 2011

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