APPLICATION OF METROPOLIS GENETIC ALGORITHM FOR THE STRUCTURAL DESIGN OPTIMIZATION

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Summary A new Metropolis genetic algorithm is developed and applied for the structural design optimization. In the algorithm, favorable features of Metropolis criterion of simulated annealing are incorporated in the reproduction operations of simple genetic algorithm. Typical numerical examples are used to evaluate the performances and applicability of the proposed algorithm and it is concluded that the proposed Metropolis genetic algorithm is a reliable and efficient tool for structural design optimization.

INTRODUCTION

Stochastic search techniques such as simulated annealing (SA) and genetic algorithms (GA) have been widely applied for the structural design optimization due to their simplicity in theortical concepts and superior searching capability in solution space. SA is a combinatorial optimization technique that does not require the continuity of functions. Hence, it is very suitable for the optimization problems with discrete design variables. It also has a favorable advantage of possible convergence to a precise global optimum. However, its major drawback lies in the time-consuming computation to reach the neighborhood of global optimum, or slower convergence.

GA has various versions such as simple GA (SGA), micro GA (μGA), hybrid GA, and others. They have been successfully applied in various fields of optimization, due to the desirable features of avoiding undesirable local optima and rapid convergence to near global optimum. However, most versions of GA have common drawbacks, i.e., since they basically search a solution space using random numbers, it is very hard to reach the precise optimum solution. Hence, different optimum solution may be obtained in every trial to get an optimum for the same problem.

Considerable amount of research efforts has been made to overcome the shortcomings of both SA and GA, but the results are not at all satisfactory in the field of structural optimization. In order to realize the advantageous features and alleviate the undesirable drawbacks of both SA and GA, the Metropolis criterion of SA may be incorporated in the reproduction operations of GA. Thus, we develop and propose a Metropolis genetic algorithm (MGA) in which both the Metropolis criterion and roulette wheel selection are used in SGA.

In the study, critical procedures of both SA and GA are firstly reviewed. Then, the Metropolis criterion, an essential process of SA, is incorporated in SGA to develop an MGA. Finally, the proposed MGA is applied for the typical numerical examples of structural design optimization and its performances and applicability are evaluated.

DEVELOPMENT OF METROPOLIS GENETIC ALGORITHM

In the conventional GAs such as SGA and μGA, the reproduction operation is performed primarily based on the individual fitness. Hence, any individual with low fitness tends to be deleted from the mating pool even if it has potential genetic information. Therefore, Metropolis criterion should be applied just before the reproduction operation, as the fitness value of each individual should be evaluated first for the reproduction.

Other genetic operations of SGA such as one-point crossover, simple mutation, and elitism can be also effectively used in MGA as they are. If Metropolis criterion is combined to any genetic operation other than reproduction, its favorable features may not be highlighted or even useless. For example, the number of function evaluation will be doubled if Metropolis criterion is combined to crossover or mutation. If Metropolis criterion is used before or after elitism, the procedure will be exactly same as the conventional GAs.

Therefore, in the study, Metropolis criterion is combined to the reproduction operator of SGA in addition to a roulette wheel selection to develop MGA. Metropolis criterion in MGA enables an individual with low fitness (i.e., less than average fitness F_a) to be possibly accepted so that the genetic varieties may be maintained in the population without losing the potential genetic information at early generations. It also prevents the convergence to a premature local optimum due to the expansion of search space. In other words, an acceptance probability of lower-fitness individual is made very high at early generations (i.e., the temperature parameter T is large enough) and the resulting solution space can be considerably extended. Thus, a global optimum may not be missed and premature local optima can be avoided as well. At near-final generations with very small T, the Metropolis acceptance probability will be considerably reduced and the acceptance of low-fitness individual is strictly limited. Consequently, the precise convergence to a global optimum is assured in MGA.

NUMERICAL EXAMPLES AND RESULTS

A class of numerical examples is investigated. Among them, an example of composite breakwater design is presented herein. For the comparison's purpose, the results of MGA, SGA, μGA, and SA are also presented and compared.

Definition of design variables and schematic diagram of cross section is shown in Fig. 1. Design objective is the unit construction cost, which consists with upright section (A_u), revetment (A_{rw} & A_{rl}), and core (A_c) of the breakwater. The constraints imposed are; sliding and overturning of upright section, bearing capacity, sliding of underwater structure, and stability of rubble mound. Design parameters and genetic operators are listed in Tables 1 and 2. Basic results are summarized in Table 3.

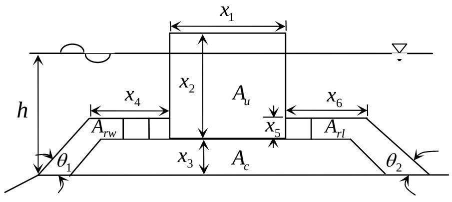

Fig. 1 Cross-section of composite breakwater.

More parametric results and examples will be presented at the conference. Among them are the algorithm capability results such as frequency of obtaining precise optimum, effects of population size and maximum generations, etc.

Table 1 Genetic operators used for SGA, μGA and MGA

GA parameters	SGA	μGA	MGA
Reproduction	Roulette wheel	Tournament	Metropolis criterion & Roulette wheel
Crossover (Rate)	One-point (0.85)	One-point (1.0)	One-point (0.85)
Mutation (Rate)	Simple (0.01)	-	Simple (0.01)
Elitism	Yes	Yes	Yes

Table 2 Parameters used for SA

SA parameters	Value
Initial temperature	1000
Final temperature	0.0001
Cooling schedule	Geometric
Cooling coefficient	0.99
Maximum inner loops	50
Boltzmann constant	1.0

Table 3 Results of composite breakwater example with SGA, μGA, MGA, and SA

Algorithm	x_1(m)	x_2(m)	x_3(m)	x_4(m)	x_5(m)	x_6(m)	Violation	Cost(m^3)	N_{opt}	P_{opt}
SGA	15.92	6.91	6.66	8.02	1.00	5.50	0.00	422.67	117960	9
μGA	15.43	6.57	7.10	8.03	0.99	5.50	0.00	429.26	4722	1
MGA	**16.10**	**6.94**	**6.63**	**8.04**	**1.00**	**5.11**	**0.00**	**421.00**	**117240**	**62**
SA	15.87	6.96	6.88	8.30	0.99	5.44	0.00	421.00	139427	-

SUMMARY AND CONCLUSIONS

In the application of genetic algorithms, the individual varieties in a population should be maintained to assure the global optimality. Any favorable genetic information inherent in early generations should never be lost during the design iterations. By keeping both of the desirable features, undesirable convergence to local minima or time-consuming computation to get a precise global optimum can be avoided. To this end, the Metropolis selection criterion of SA is incorporated in the reproduction process of SGA to develop an MGA.

The resulting MGA is proposed for the structural design optimization and its behavior and performances are evaluated using typical structural design examples. Applicability and robustness of MGA are evaluated through a series of numerical investigations with the parameters such as population size and maximum number of generations. The results are compared with those of SA, SGA, and μGA, and the following conclusions are drawn:

1) The results of numerical examples show the superior applicability of the proposed MGA to other stochastic algorithms.

2) A combinatory reproduction operation with the Metropolis criterion and roulette wheel selection enhances the convergence property of MGA, i.e., excellent capability to get a precise global optimum and faster convergence. Hence, the performance of the proposed MGA is more efficient than other single algorithm.

3) Through a parametric study with population sizes and maximum generations, the proposed MGA is shown to be robust and reliable comparing to other versions of GA.

4) It is also concluded that the proposed MGA can also be effectively applied for the real-world problems of structural design optimization.

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