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SIMULATION OF EARTHQUAKE GROUND MOTIONS COMPATIBLE WITH MULTI-DAMPING-RATIO-SPECTRA BASED ON GENETIC ALGORITHMS

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SUMMARY

The artificial seismic waves used in seismic design should satisfy multi-damping-ratio-spectra simulation requirements. Present simulation methods of the ground motions are suitable for single-damping-ratio-spectrum simulation, but the simulation precision is not satisfactory for multi-damping-ratio-spectra simulation. In fact, there should be different design spectra corresponding with the structures of different damping ratios, the new Code for Seismic Design for Buildings, GB50011-2001, of China has provided corresponding spectra for structures with different damping ratios. Obviously, the artificial ground motions used for structural time history analysis should be well coincided with multi-damping-ratio-spectra.

Based on the comparison of the conventional algorithms with the multi-objective optimization and genetic algorithms, a method for the simulation of multi-damping-ratio-spectra is proposed in this paper, which combines the multi-objective optimization algorithms and genetic algorithms. The program proposed is examined by several examples including actual earthquake records and artificial seismic waves. The simulation precision of the method is checked by many aspects such as intensity, spectra, and parameters of ground motion. The precision of simulation of ground motions compatible with multi-damping-ratio-spectra has been improved comparing with the conditional one. The Pareto optimal solution set can be obtained conveniently which is difficult by the conditional one. The results show that the method has much more advantages over the traditional methods and it's adequate to meet the needs of simulation of ground motions compatible with multi-damping-ratio-spectra in seismic design.

INTRODUCTION

Artificial seismic waves are often used as input in seismic structural design, therefore artificial seismic waves should be simulated from given objective spectra according to earthquake circumstance of sites. The most commonly used method is the trigonometric series method presently. But the results of simulation of the actual record indicate that the simulation precision of actual record and the artificial

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wave obtained from objective spectra, which is gotten from the actual record through simulation of some given single-damping- ratio-spectra (for example 5%), on the object spectra for a given damping ratio is higher than that on the other damping ratio spectra. Especially for the lower damping-ratio-spectra (for example 2%), the error will be greater on the high-frequency section of spectra [1] [2] [3]. In fact, the information of actual earthquake motion cannot be represented by the artificial wave generated by conventional method.

Moreover, with the varieties of building structure styles and structure materials as well as the application of components for the absorption of energy and vibration, the damping characteristics of structure change obviously. In the seismic structural design with different damping-ratios, the inputted seismic waves should be compatible with the corresponding damping ratio spectra. While the spectra with different damping-ratios at the same site are also different, different artificial seismic waves are generated from the conventional artificial wave method simulating single-object-spectra. For example, artificial waves simulating 2% damping-ratio-spectra are applied to the design of steel structural buildings, but for the design of concrete structures, artificial waves simulating 5% damping-ratio-spectra should be used. The spectrum characteristics of the two kinds of seismic waves are obviously different with same seismic circumstance. So there are contradictions when different seismic waves are used to represent the degree of seismic risk with the same circumstance. Therefore it is difficult to choose the inputted seismic waves. One of the ways to solve the problem is to apply the artificial seismic wave simulating multi-damping-ratio-spectra for the input of time history analysis. So simulation of multi-damping-ratio-spectra should be given enough concerns [4].

Actually the simulation of earthquake ground motions compatible with multi-damping-ratio-spectra is an issue about multi-objective optimization in data processing. For this purpose, the latest popular genetic algorithm is introduced in this paper .The method is proved to be feasible through analysis of examples.

GENETIC ALGORITHMS AND MULTI-OBJECTIVE OPTIMIZATION

Overview of genetic algorithms

Genetic algorithms, evolved from biologic genetics and natural selection theory, is a typical searching-algorithm of self-adapting colony-model and iterative random optimization [5] [6]. Through some cross operators and variation operators, the method generates a next generation. Then choose the operator and quality individual to form the next population in terms of individual adaptability. So the repetitive iterations should be done until a satisfactory precision is reached. This algorithm uses population search instead of individual search of the traditional method [7]. So it does not fall into partial optimization .The algorithm directly regarded the feasible solution of the problems as the solution of individual. It doesn't need to encode and decode for individual, and doesn't have to take the factor of random perturbation affecting each individual into account. It is suit for optimization problem among the N-dimension real number space [7] [8].

Concept of multi-objective optimization

The common mathematical model of multi-objective optimization with P objective functions can be shown as [9],

$$\begin{cases} \min\left\{f_1(x), f_2(x), \cdots, f_p(x)\right\} \\ g_i(x) \le 0(i=1,2,\cdots,m) \quad ¡¡¡¡ \\ h_j(x) = 0(j=1,2,\cdots,k) \end{cases} \qquad ¡¡(1)$$

Where x is a point among the n-dimension Euler space E^n, that is, $x=(x_1,x_2,\cdots x_k)\in E^n$; $g(x)$ and $h(x)$ are constraint functions.

According to the equation (1), the purpose of multi-objective optimization is the optimization of components in the object vector function. Therefore, differential from the single-object optimization, the solution to this problem is not a point but a point-group called Pareto optimum or Pareto quasi-optimum. Pareto optimum solution set means that improvement of one component for each point among the solution set will result in the failure of one another component at least [9]. Theoretically, every solution among the Pareto optimum solution sets may be considered to be the optimum solution to the problem, which is up to decision maker's preference. Figuring out a subset that approximates the Pareto optimum solution set as soon as possible can be a foundation for a split solution that satisfies the decision maker. Therefore working out a Pareto optimum solution set is the first step to resolve the problem of multi-objective optimization. The traditional way to handle the problem of multi-objective optimization is to invert the issue into a single-object optimization problem. For example, the method of linear weighted sum, the method of ideal point, and so on. But how to confirm the weighted coefficient is a difficult problem for these methods, and there are some difficulties in obtaining an ideal solution of complex problems.

Treatment of multi-objective optimization

The key of genetic algorithms dealing with multi-objective optimization issue is the choice of the competitive strategy. Single objective optimization has one objective function only; the merits and weaknesses of individual are obvious. Performing multi-objective optimization, the individual's quality should be distinguished according to Pareto optimum definition. Document [10] proposes one called Pareto arrange multi-objective competitions option mechanism. The process of Pareto arrange is: each individual $\bar{x}_i$ in colony compare with r individual in colony chosen at random separately and statistic the quantity of p optimized objective-function which superior to the definite $\bar{x}_i$ in r individuals (wrote for ϖ_i, obviously $\varpi_i \geq 0$). The superior number $\bar{x}_i$ can be regarded as sufficiency F_i of multi-objective optimizing evolutionary algorithm. According to Pareto optimum definition that to every Pareto optimum, its sufficiency is $F_i = 0$. Through the above-mentioned Pareto arrange, change p optimizing objective function $f_1(\bar{x}), f_2(\bar{x}), \cdots, f_p(\bar{x})$ of multi-objective optimization to single-objective optimization problem for the objective F_i. Multi-objective optimization process is to make whole adaptation F_i tend towards extremely small, which is also the process of the evolutionary colony constantly approaching to the convergence of Pareto border.

Based on above explanations, a new multi-objective genetic algorithm method can be formed through combining genetic algorithm with multi-objective optimization. The method is used to simulate multi-damping-ratio-spectra.

METHOD OF SIMULATION OF EARTHQUAKE GROUND MOTIONS COMPATIBLE WITH MULTI-DAMPING-RADIO-SPECTRA BASED ON GENETIC ALGORITHMS

On the base of simulation of ground motion of single-objective-ratio-spectra (called trigonometric series method), the simulation of earthquake ground motions compatible with multi-objective-radio-spectra is completed by inducing genetic algorithm. Its basic trains of thought and method are,

(1) Earthquake acceleration course is regarded as the even course of modulating

$$a(t) = f(t) \cdot x(t) \tag{2}$$

In the formula, *a(t)* is earthquake acceleration time history, *f(t)* is the intensity enveloping curve function established in advance, and $x(t)$ is stable process which can be shown by the form of limited trigonometric series sum.

$$x(t) = \sum_{k=0}^{n} C_k \cos(\omega_k \cdot t + \varphi_k) \tag{3}$$

In the formula, C_k and φ_k are random amplitude and phase angle respectively of harmonic component with frequency φ_k. Usually φ_k is among $0 \sim 2\pi$ for uniform distribution;

(2) According to multi-objective issue construct optimized objective function, for random amplitude C_k (every group of array is called an individual);

(3) According to genetic algorithm construct the initial random colony formed by different arrays C_k ;

(4) Calculate each objective function value, individual sufficiency and sharing function; value and execute cross, variation, optional operation of the evolutionary strategy algorithm, generating new individual and colony;

(5) Return the 4th step, until the precision meets the requirement.

The process of multi-damping-ratio-spectra simulation is not more than the process of obtaining proper amplitude series. When using genetic algorithms to simulate single-objective-spectra with adjusting amplitude series by error control, it is easy to bring obstinate point. In this paper, genetic algorithm is used to search the optimal max value of amplitude series. That is, take single max value of spectra C_k as chromosome which composed unit in frequency order. Every unit represents an item of seismic wave. By calculating the sufficiency value according to the difference between response spectra and objective spectra, creating new unit through cross operator and variant operator, showing the relationship of objectives through multi-objective-competitive-select method of Pareto arranges and select better unit as next generation, and making solution of the unit more equal to the Pareto optimal solution according to evolutionary operator until finding satisfactory solution, the solution that supplied by the method is optimal solution. An item of seismic wave that can satisfy given request will be found for every unit in the solution set. Artificial seismic wave set which simulating multi-objective response spectra will complete at one time in actuality through the method recommended in this paper. Compared with conventional method that must iterate in order to induce an item of seismic wave, the method recommend in this paper is obviously effective.

SIMILARITY VALIDATION OF SIMULATING SPECTRA OF STRONG GROUND MOTION RECORDS AND ARTIFICIAL SEISMIC WAVES

Simulating spectra of strong ground motion records

In order to validate the feasibility and advantage of the method in simulating the earthquake ground motions, simulations of some actual record showed as Figure1 are done respectively with the method presented in this paper and the traditional trigonometric series method. Here the artificial seismic waves are obtained from response spectra.

The method, recommended in this paper (simplified as case 4), is used under the condition that group scale M =15, cross probability of unit P_c=0.85, variable probability P_m=0.35. Conventional trigonometric series method is only suitable to simulate single-objective spectra, so compare with the below results of three situations respectively in order to estimate completely the results calculated by the method in this paper.

(1) Simulative result of traditional trigonometric series algorithm used 5% damping-ratio-spectra as object spectra (simplified as case 1);

(2) Simulative result of traditional trigonometric series algorithm used 2% damping-ratio-spectra as object spectra (simplified as case 2);

(3) Simulative result of traditional trigonometric series algorithm used 5% and 2% damping-ratio-spectra as object spectra (simplified as case 3).

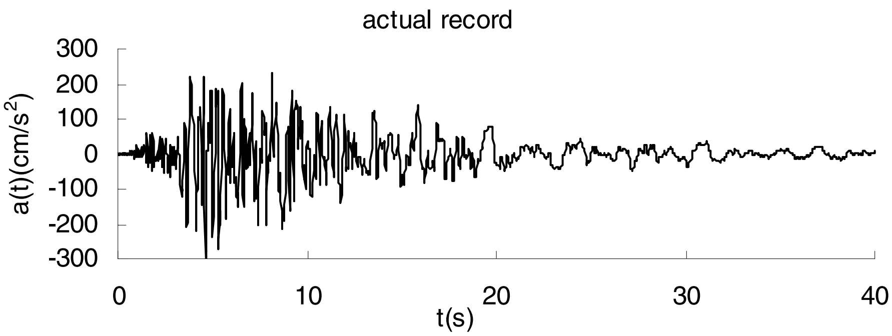


Figure 1. A ground motion record used for the analysis

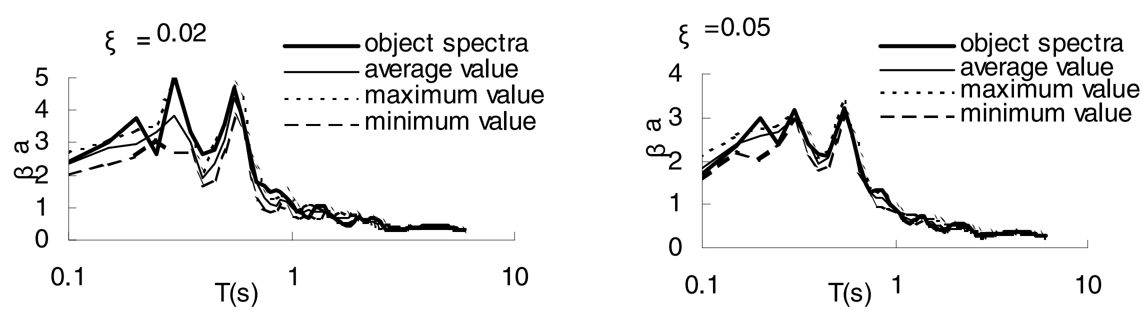
Figure2 and Figure3 show the comparison of simulation by the pervious 4 cases about 15 items of artificial seismic wave. It is can be seen that,

(1) The precision of conventional method is passable in simulating single damping ratio, but the error becomes too large when simulating another damping ratio non-objective response spectra, therefore the phenomenon, attend to one and lose another, appears;

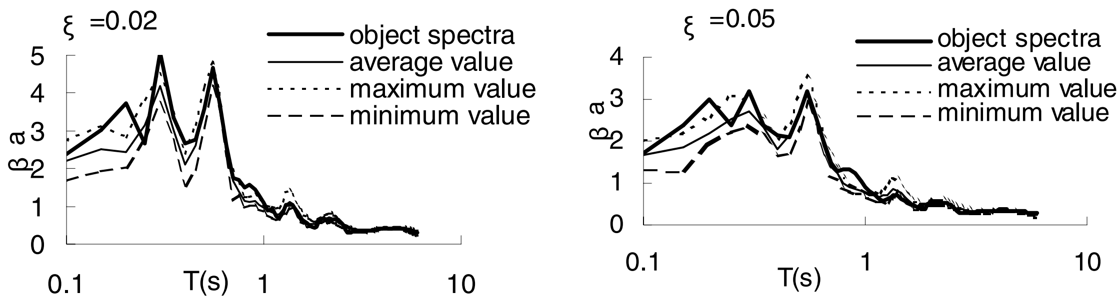
(2) Conventional method can equilibrate simulation error of all damping ratio response spectra to an extent while simulating average response spectra of multi-damping-ratio response spectra, but the equilibrium is at the cost of losing whole precision;

(3) The method in this paper can consider the simulative precision of different ratio spectra at one time. It perfectly resolves the problem of simulating multi-damping-ratio-spectra, which exists in the traditional algorithm.

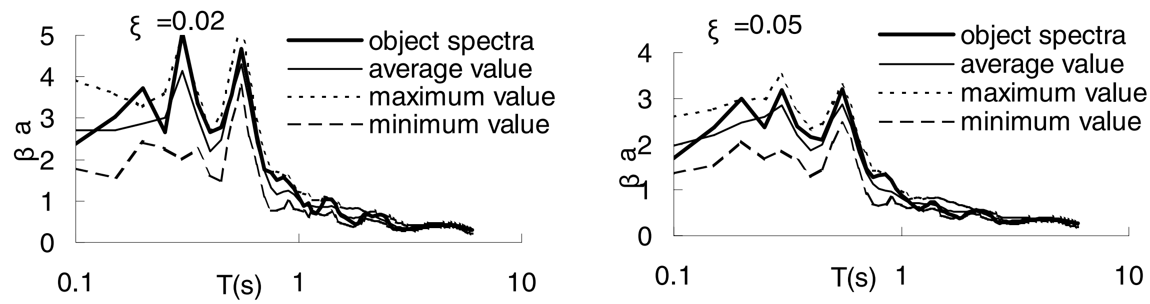
Therefore simulative precision for the artificial waves, based on method of simulation of earthquake ground motions compatible with multi-damping-ratio-spectra based on genetic algorithms, is improved greatly, compared with the traditional trigonometric series method. Furthermore when the method is implemented once, the Simulation of earthquake ground motions compatible with multi-damping-ratio-spectra will be completed. Work efficiency is improved greatly compared with the traditional method, especially for determining seismic waves in the multi-wave checking calculation of engineering structures.



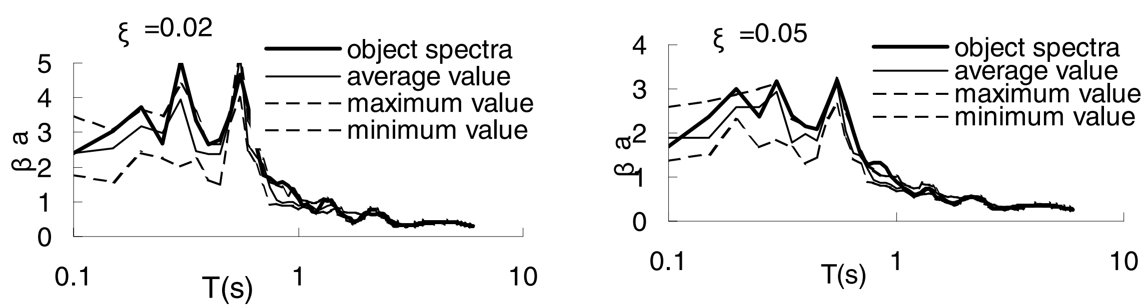
(a) Simulative result of traditional trigonometric series algorithm used 5% damping-ratio-spectra as object spectra



£¨b£©Simulative result of traditional trigonometric series algorithm
used 2% damping-ratio-spectra as object spectra



(c) Simulative result of traditional trigonometric series algorithm
used 5% and 2% damping-ratio-spectra as object spectra



£¨d£©Simulative result of trigonometric series algorithm in this paper
used 5% and 2% damping-ratio-spectra as object spectra

Figure 2. Comparison of results between genetic algorithm and the traditional method

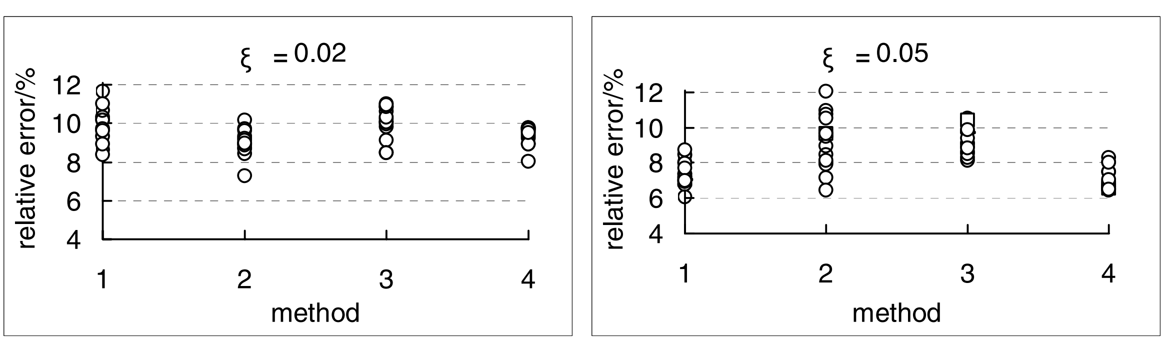


Figure 3. Comparison of simulative error between genetic algorithm and the traditional method

Similarity validation of earthquake waves

Except for response spectrum, the other characteristics of ground motions of the artificial wave are supposed to be satisfied with that of the actual record. In order to validate the comparability between the artificial wave and the actual record, three types of comparison have been presented, that is, the comparison of the artificial wave and actual record, the comparison of the Fourier spectra, and the comparison of the parameters of ground motions.

The comparison of the curve between actual record and the artificial wave generated by the method in this paper is shown in Figure 4. In the two cases, the shape and the frequency of wave are very similar, but there are some differences between the amplifications.

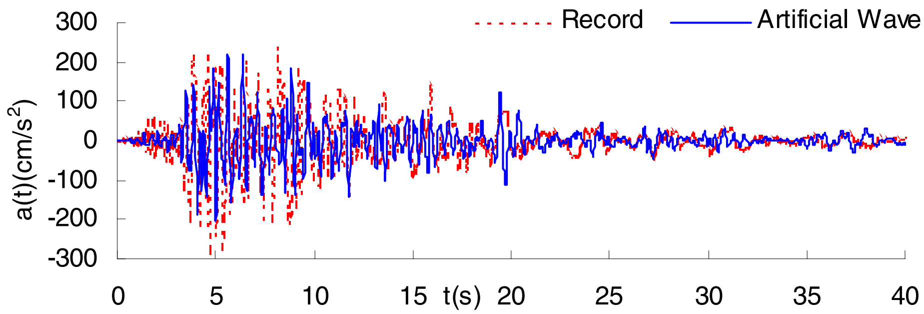


Figure 4. Comparison of the record and the artificial wave

The comparison of the Fourier spectrum between the recorded wave and the artificial wave generated by the method in this paper is shown in Figure 5. In the two cases, there are some differences between the components of frequency. There are more high frequency components in the artificial seismic waves, probably the non-stationary characteristics of frequency are not considered, and the method can be improved by adjusting zero-crossing ratio.

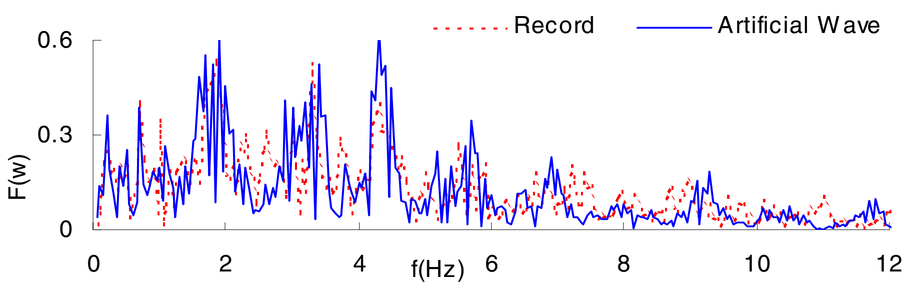


Figure 5. Comparison of Fourier amplitude spectra of the record and the artificial wave

The comparison of the parameters of ground motions between the artificial waves and the recorded waves is shown in Table 1. The comparison cumulative numbers of zero-crossing is shown in Figure 6 and the comparison of normalized Husid diagrams is shown in Figure 7. The parameters of ground motions between the artificial waves and the recorded waves are very close.

Table 1 Comparison of the parameters of ground motions

	PGA (m/s^2)	RMSA (m/s^2)	SI (m)	AI (m/s)
Object value	0.810	0.321	0.6091	0.1114
Ave. value	0.790	0.302	0.5865	0.1034
Max. value	0.830	0.332	0.6254	0.1226
Min. value	0.740	0.298	0.5357	0.08456
Standard deviation	0.0114	0.045	0.6670	0.245

Note: PGA is peak amplification value of acceleration,

RMSA is mean square root of the amplification value of acceleration,

AI is Arias intensity,
SI is Housner spectrum intensity.

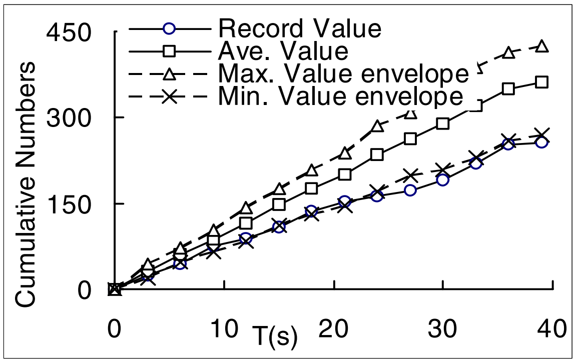


Figure 6. Comparison cumulative numbers of zero-crossing

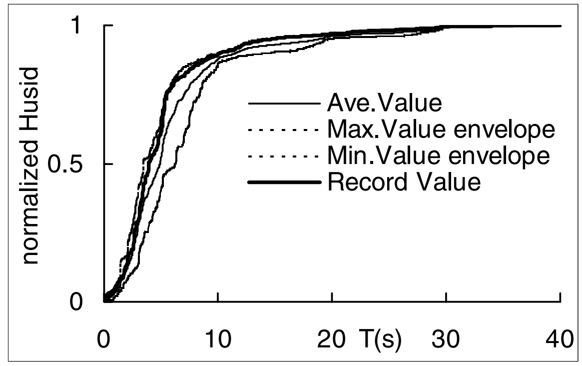


Figure 7. Comparison of normalized

Based on similarity validation of artificial seismic waves, the method in this paper not only obviously improves the simulation precision of spectra, accordingly settle the issue about simulation compatible with multi-damping-ratio-spectra, but also makes artificial seismic waves contain main characteristics of earthquake ground motions simulated.

CONCLUSIONS

Through introducing the conception of multi-objective optimization solution in this paper, the difficulty for the determining the relationship among the objectives on the multi-objective optimization subject, is resolved properly. Moreover the multi-objective genetic algorithm is formed by combining this method with genetic algorithm. If this method is applied for simulation of earthquake ground motions, a new method which is known as simulation of ground motions compatible with multi-damping-ratio-spectra based on genetic algorithm is put forward. As shown from the above examples, compared with the traditional artificial wave method, the new method is improved at the aspects of precision and searching efficiency. It not only clears the obstacle in traditional method on the simulation of multi-damping-ratio-spectra, but also obtains a group approximate Pareto optimal solution set which has a characteristic of set system in seismic design .The method and idea introduced in this paper can also be applied to poly-dimensional and spatial simulation of ground motions.

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