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Soft Computing in Earthquake Engineering: a Short Overview

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Abstract – *Soft Computing refers to the name for solving the hardest problems with which human are confronted today that tolerates the imprecision, uncertainty, partial truth, and approximation of the solutions. Nature inspired algorithms, like evolutionary algorithms, swarm intelligence, and neural networks become one of the leading methods for solving these problems. The soft computing methods have also been applied for solving the earthquake engineering problems. In this paper, a short review of these methods is presented. In line with this, the problems solved by soft computing algorithms are identified, then, the characteristics of these algorithms are exposed and finally, the applications of the soft computing algorithms are identified. The paper concludes with an overview of the possible directions for further development.*

***Keywords**: Earthquake Engineering, Optimal Seismic Design, Earthquake Prediction, Data Analysis*

I. Introduction

An aim of earthquake engineering [1] is to consider the structures [2] as well as geo-structures [3] during a seismic load. Seismic load causes earthquake-generated excitations on structures. The earthquake engineering deals with consequences of seismic loads and belongs to a part of a civil engineering. On the other hand, the effects of the seismic load have also social consequences.

Today, the fast development of computer science has been caused that methods from this area have also been applied to other areas of human activities. This process could not be avoided even by earthquake engineering.

Primarily, two problems have been solved by so named soft computing in earthquake engineering, i.e. searching for an optimal seismic design of structures, and earthquake prediction from data analysis. The former proposes the novel materials and/or construction methods in order to prevent a demolition of the structures, while the latter try to predict the time, location and magnitude of forming the earthquake from data analysis.

This paper brings a short overview of soft computing methods in earthquake engineering. Soft computing refers to solving the hardest problems with which human are confronted today that tolerates the imprecision, uncertainty, partial truth, and approximation by searching for the solutions. This class of algorithms comprises mainly the nature inspired algorithms, like evolutionary algorithms (EA) [4], swarm intelligence (SI) [5] and artificial neural networks (ANN) [6]. In line with the identified problems in earthquake engineering, the optimal seismic design of structures is performed with EA and SI algorithms, while the earthquake prediction is more suitable for modeling/simulation with ANN.

The structure of the remainder of this paper is as follows.

In Section II, the problems in earthquake engineering are classified. Section III deals with characteristics of soft computing algorithms in the earthquake engineering, while Section IV reviews the papers from this domain.

The possible future directions of development are discussed in Section V. The paper concludes by summarizing the performed work.

II. Problems in Earthquake Engineering

Earthquake Engineering can be defined as the branch of civil engineering devoted to mitigating earthquake hazards [7]. In this broad context, it covers the investigation of problems occurred when earthquake has been arisen, and searching for the solutions minimizing a damage of its activities.

The former covering has been led to earthquake prediction, while the latter to development of the optimal seismic design of objects. A whole taxonomy of problems arisen in earthquake engineering that are appropriate for solving with soft computing algorithms is presented in Fig. 1. As can be seen from Fig. 1, the soft computing algorithms have been focused on solving the two kinds of problems:

- searching for the optimal seismic design of structures;
- earthquake prediction from data analysis.

While the former refers to the problem optimization according to a system analysis, the latter addressed the problem of modeling/simulation.

The optimization of seismic design deals with passive and active structures in order to reach the earthquake safety. On the other hand, the earthquake prediction can be performed either from the real-time history series of seismic data obtained by the seismographs or this prediction of the ground motion is modeled using the attenuation relations. In the remainder of this section, the taxonomy of the earthquake problems is elaborated more detailed.

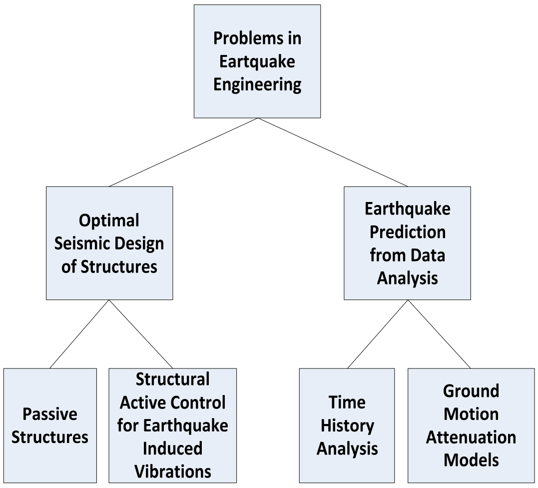

Fig. 1. Taxonomy of problems arisen in earthquake engineering

II.1. Optimal Seismic Design of Structures/Buildings

Earthquake are results of slippage along a fault plane, often well below the surface of the earth [8]. This surface faulting may results in large earth movements. Therefore, structures located across a surface fault usually suffer severe damage that may lead even to them demolition.

As a result, people avoid building the structures on locations sensitive of geological hazards.

Unfortunately, on some locations on the earth peoples must be accustomed with the risk of earthquakes, e.g., Japan, Indonesia, China, etc. There, a civil engineering has put against the fact how to mitigate or even eliminate the effects of the ground motion.

Let us assume a structure located on the surface sensitive to geological hazards. This structure can be built on two ways. One way is to build the structure using the elastic earthquake safe materials that are naturally very expensive. This kind of building structures is also named as a *passive* approach. The alternative way is to use a set of actuators and sensors connected by a feedback loop [9]. In this case, the structure is able to adapt to the demolition activity of the ground motion.

Therefore, this structure is known as *active*.

II.1.1. Passive Earthquake Safe Structures

Passive control techniques are mainly divided into two parts of absorption and dissipation [10]. Tuned Mass Dampers (TMDs) and mechanical energy dissipaters (e.g., viscous fluid dampers and viscoelastic solid dampers) could be classified as passive energy dissipation systems.

The principal function of a passive energy dissipation system is to reduce the inelastic energy dissipation demand on the framing system of a structure [11].

The analysis results of Shayeghi et al. [12], reveals that the designed Particle Swarm Optimization (PSO) based TMD controller had an excellent capability in reduction of building response under earthquake excitations.

However, most of the passive dampers can be used to tune only a given fixed frequency of vibration, normally the fundamental frequency of vibrations of a structure [13]. Sometimes, these tuned values will not match with the input excitation and the corresponding structure response (e.g., in a Multiple-Degree-of-Freedom (MDOF) structure). This is the major disadvantage of the passive dampers, which can be overcome by using multiple passive dampers, each tuned to different frequencies or by adding an active control to it [14].

On the other hand seismic (base) isolation system is categorized as energy absorption system. The principle of seismic isolation is to introduce flexibility at the base of a structure in the horizontal plane, while at the same time introducing damping elements to restrict the amplitude of the motion caused by the earthquake. Mechanical energy dissipaters in parallel with a base isolation device can control the response of the structure by limiting displacements and forces, thereby significantly improving seismic performance [15].

The addition of damping, however, may also increase the internal motion of the superstructure as well as increase absolute accelerations, thus eliminating many of the gains base isolation is intended to provide [16]. Ozbulut and Hurlebaus [17] propose two Fuzzy Logic Controllers (FLCs) for operating control force of piezoelectric friction dampers used for seismic protection of base-isolated buildings against various types of earthquake excitations. Results for several historical ground motions show that developed fuzzy FLCs can effectively reduce isolation system deformations without the loss of potential advantages of seismic base isolation.

II.1.2. Structural Active Control for Earthquake Induced Vibrations

As already said, active control system, when used in combination with a passive control device, can cover many disadvantages of passive systems. Consequently, the effects of the active control are obviously superior to the passive control in decreasing the response of structure vibration. Active structural control systems are a natural evolution of passive control technologies. Actually, active control system by using external power, act simultaneously with the hazardous excitation to provide enhanced structural behavior for improved service and safety [18]. Efficient active control systems can be implemented with existing technology under practical constraints such as power requirements, maintenance and stringent demand of reliability [19]. Schmidt [20] presented the synthesis of an active control system using a modified PSO method. PSO method efficiently incorporated the constraints on the active system's stability and the maximum output of actuators.

In addition, Guclu and Yazici [21] designed FLC for a MDOF structure with two types of actuators, to suppress earthquake-induced vibrations. The results of this study, showed a good performance by the FLC for different loads and the earthquakes.

II.2. Earthquake Prediction from Data Analysis

Earthquake prediction refers to report of warning against the earthquake hazards. This warning can be predicted at most a few days or even a few years to a few decades in advance. The former is also denoted as 'short-term' prediction, while the latter refers to a 'long-term' prediction. Both kinds of prediction serve as tools that enable people to permit measures such as evacuation.

The earthquake prediction serves as a very hard task, because the earthquake is a non-liner process that is highly sensitive to un-measurable fine details of the Earth state. Therefore, Geller in [22] at 1997 wondered if the earthquake prediction is even possible. However, the rapid development of the new technologies, e.g., seismology, computer science, global positioning system (GPS), etc., enable that this prediction would become accurate in the future. In seismology, the nature of ground motion affecting the building can be conceptually described as follows. Earthquake is arisen in fault rupture that generates the waves. These waves that create motion are spread from the epicenter in all direction. A magnitude of this ground motion decreases with the distance from the epicenter, while the ground motion.

The ground motion has a random nature and can even be transmitted in emphatic direction. Typically, this motion affects the building using horizontal and vertical component. Which of these components is more destructive for the building depends on the specific situation.

II.2.1. Time History Analysis

A ground motion models has been developed in order to simulate the destructive consequences of the real-world earthquakes. This simulation serves as a prediction tool of earthquake strength that is used for searching for the optimal seismic design of structures. Usually, real-time series data of seismic event earthquake are applied for the modeling/simulation (i.e., training and testing).

These data is also known under a name time history data, while an analysis of these data is known under the name time history analysis (THA). The data included local, regional, and quarry-blast events with epicenters determined by their longitudes and latitudes. Each dataset is identified by depth of earthquake, time of occurrence, geographical area, and magnitude of earthquake.

II.2.2. Ground Motion Attenuation Models

Complexity of usage and in this respect, duration of computation cause that the prediction of ground motion attenuation has been emerged.

This prediction results from a large scenario earthquake and it is of fundamental importance to earthquake engineering as well as soft computing algorithms that have been arisen in this domain.

Thus, attenuation relations are frequently employed.

These relations describe the dependence of the strength of the ground motions on the earthquake magnitude and on the distance from the earthquake.

III. Characteristics of Soft Computing Algorithms for Earthquake Engineering

In system analysis [4], the problems are threat as a system consisting of: input, model, and output (Fig. 2).

According to one of the unknown components of the system, problems are divided into following types:

- optimization,
- modeling,
- simulation.

In optimization problem, an optimal input is searched for a known model and an output. Generally, the optimization problem is defined as quadruple $P = (I, S, f, goal)$, where *I* denotes a set of instances, *S* is a set of feasible solutions, *f* an objective function that can be either minimized or maximized according to a *goal*.

Typically, the optimal seismic design of structures is solved using soft computing algorithms in the earthquake engineering.

Modeling tries to describe a real-world system on formal way.

Typically, this formal way presents mathematical or physical equations which determine the behavior of the system. Therefore, such model needs to reflect characteristics of the real-world system that inspired it. Earthquake is strong random dynamic process. Therefore, the earthquake model is subject of uncertainty. Consequently, this model must be stochastic in nature.

Earthquake simulation describes how system (i.e., structure) responds to uncertainty caused by ground motion. In fact, it produces only estimates of system performance.

Selection of characteristic patterns on input depends on the ability and intuition of human/machine performing the simulation. However, a task of simulation is to find the optimal patterns in the specific model.

Interestingly, algorithms in earthquake engineering consist of components for solving all three types of problems.

That is, the optimization of seismic design is performed in dynamic environment that is simulated by earthquake simulation component, where the simulation relies on the programmed prediction model (Fig. 3).

However, the prediction model bases either on the time history analysis or the ground motion attenuation relations.

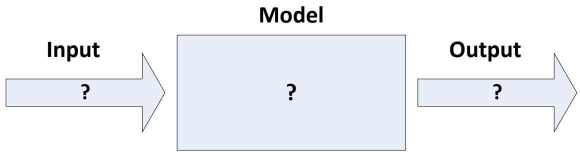

Fig. 2. Problems in system analysis

Fig. 3. Soft computing algorithms in earthquake engineering

Typically, the problems in earthquake engineering are solved using the soft computing algorithms. The term of soft computing was introduced by Zadeh [23] in 1992 and refers on the collection of methodologies that solve the problems without an extensive mathematical formulation [24] (in contrast to hard computing).

The algorithms in soft computing tolerate the imprecision, uncertainty, partial truth, and approximation. They are adaptive in their nature and therefore, suitable for solving the problems arisen in dynamic environments. Mainly, the following families of algorithms are considered into the soft computing algorithms:

- evolutionary algorithms (EA) [4],
- swarm intelligence (SI) [5],
- artificial neural networks (ANN) [6].

EA imitates a Darwin's evolutionary theory [25], where the fitter individuals have more chances to survive in a struggle for survival. In general, they are population-based, where each individual consists of elements, i.e. genes. Individuals suffer from acting the evolutionary operators in each generation, i.e., crossover and mutation.

Usually, crossover generates two offspring from two parents, while mutation modifies a specific element of the individual randomly. Each individual is evaluated after variations.

Thus, a fitness function is applied. It is connected with a problem to be solved. A selection operator selects the fittest individuals for the next generation of the evolutionary process. The EA are divided according to different representation of individuals in the following types:

- Genetic Algorithms (GA) [26],
- Genetic Programming (GP) [27],
- Evolution Strategies (ES) [28],
- Evolutionary Programming (EP) [29],
- Differential Evolution (DE) [30].

Also SI has been inspired by biology. In this case, an inspiration presents on the first look simple creatures that are able to perform some inherent actions. However, together in group, they are suitable to perform complex tasks, e.g. building magnificent nests by termites. For instance, ants live in groups because of searching for a food. Communication between they is carried out indirectly using a chemical substance a pheromone, which amount determines the shortest path to the food.

The SI algorithms are also population-based and act slightly different with regard to EA. Here, the population of individuals (particles) flies across the search space. Each particle moves towards the position of the best particle and thereby discovers a new possible more promising region of the search space.

The position is evaluated with the fitness function that reflects the nature of the problem. Mainly, the following algorithms have been arisen in SI domain:

- Particle Swarm Optimization (PSO) [31],
- Artificial Bee Colony (ABC) [32],
- Firefly Algorithm (FA) [33], [34],
- Harmony Search (HS) [35],
- Ant Colony Optimization (ACO) [36].

Human brain serves as an inspiration for working the ANN. These consist of enormous number of neurons that communicate with each other using the electrical impulses. In this manner, human brain may be viewed as a complex parallel computer, while the artificial neuron was modeled on the principles of biological neurons.

ANN is modeled using two or more layers (usually three) of neurons. A static ANN does not use any feedback, while a dynamic ANN adapts itself based on the principle of error minimization.

The ANN is especially suitable for classification problems, where the input patterns are transformed into output signals according to neuron parameters (weights) that have been learned during the training phase [24].

Today, various types of neural networks are employed as follows:

- Feed-Forward Neural Networks (FFNN) [37],
- Recurrent Neural Networks (RNN) [38],
- Stochastic Neural Networks (SNN) [39],
- Modular Neural Networks (MNN) [40].

In the earthquake engineering, a new FFNN networks have been applied, like Multi-Layer perceptron (MLP) [41], Radial Basis Function Networks (RBFN) [42], Self-Organized Maps (SOM) [43], Counter-Propagation NN (CPNN) [44] and Probabilistic NN (PNN) [45].

IV. Applications of Soft Computing Algorithms in Earthquake Engineering

As already said, typical soft computing algorithms in earthquake engineering include both the optimization as well as modeling/simulation component. The former is devoted for searching the optimal seismic design of structures that suffers of demolition effects of ground motion caused by earthquakes. These effects are modeled and simulated by the latter. Normally, the optimization is performed by EA and SI, while the modeling/simulation by ANN. Typically, the algorithms presented in Fig. 4 have been applied to search for optimal seismic design of structures. As can be seen from Fig. 4, EAs are represented with GA and GP, while the PSO, ABC, FA, and HS are the most popular SI algorithms in earthquake engineering. Interestingly, also simulated annealing (SA)

[46] has been applied to this domain. The SA belongs to the traditional algorithms that search for the one solution only. On the other hand, the modeling/simulation of the ground motion attenuation has mostly been performed by algorithms presented in Fig. 5.

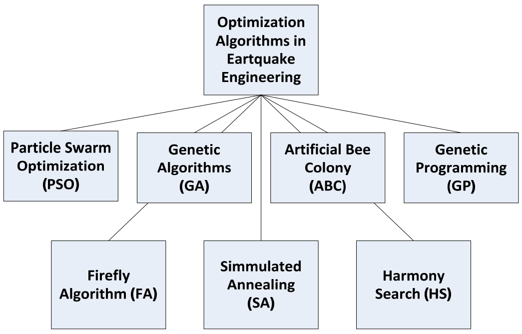

Fig. 4. Soft computing algorithms in earthquake engineering

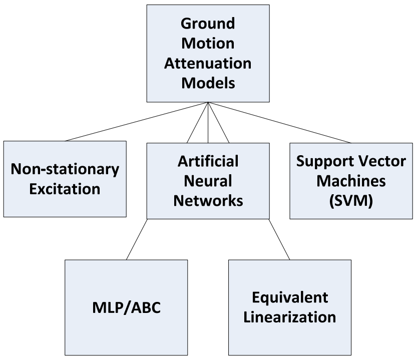

Fig. 5. Soft computing algorithms in earthquake engineering

Usually, non-stationary excitation is employed into the soft computing algorithms in earthquake engineering.

More reliable is modeling/simulation using ANN, and support vector machines (SVM) [47]. Furthermore, the meta-heuristic approach can also be detected, where parameters of the MLP are controlled by the ABC algorithm. Finally, equivalent linearization is a mathematical tool developed by Krylov and Bogoliubov [48] that is suitable for simulation of nonlinear dynamic systems with random excitation [49].

This short review of soft computing in earthquake engineering collects the more important papers from this domain, where the most frequently combination of optimization and modeling/simulation algorithms was identified. Papers tackling the earthquake optimal seismic design of structures can be seen in Table I.

Table I consists of four columns that denote: the optimization problem solved in the paper (column *Problem*), optimization algorithm used for solving this problem (column *Opti. Alg.*), modeled and simulated ground motion (column *Ground Motion*), and the reference of the paper, where this algorithm was published. The rest of the soft computing algorithms tackling the earthquake engineering deals with prediction and modeling/simulation. These papers are presented in Table II.

TABLE I
EARTQUAKE OPTIMAL SEISMIC DESIGN OF STRUCTURES

Problem	*Opti. Alg.*	*Ground Motion*	*Ref.*
Seismic resistance	Traditional	NONE	[50]
Tuned mass damper	PSO	Non-stationary	[51]
Real steel structure	PSO+AVSP	RBF	[52]
Arch dam	SPSA+PSO	Non-stationary	[53]
Linear systems	PSO	Random	[54]
RC frames	PSO	THA (Iranian)	[55]
RC frames	Monte Carlo	SVM	[56]
Record selection	HS	THA (PEER)	[57]
Real steel structure	CSS+IHS	THA	[58]
Viscous dumpers	ABC+SPSA	THA	[59]
Weight of structure	BPSO	RBF	[60]
Plan steel share	PSO	RBF	[61]

TABLE II
EARTHQUAKE PREDICTION AND MODELING/SIMULATION

Problem	*Opti. Alg.*	*Ground Motion*	*Ref.*
Seismic location	PSO+GA	Eq. waveform	[62]
Seismic location	PSO	THA (Himalaya)	[63]
Predict magnitude	NONE	PNN	[64]
Simulation	FA	THA (Tropical rainfall measuring)	[65]
MLP Training on THA series data	NONE	MLP/ABC	[66]
Predict PGA,PGV,PGD	SA	THA (PEER)	[67]
Predict PGA, PGV, PGD	GP/OLS	THA (PEER)	[68]

Four problems solved by soft computing algorithms can be identified in Table II as follows:

- predict seismic location and earthquake magnitude,
- earthquake modeling/simulation,
- generation of THA sequences,
- prediction of parameters PGA, PGV and PGD during the ground motion.

For the earthquake prediction, the soft computing algorithms are primarily used for predicting the seismic location (i.e. earthquake epicenter) [59], [62] and for predicting values of the some ground motion parameters [67], [68]. The earthquake epicenter is the point on the earth's surface directly above where the faulting and energy releases firstly begin [8].

Prediction of earthquake magnitude refers on the determining the largest earthquake in a pre-defined future time period in a specific seismic region. This prediction bases on the mathematical computed parameters known as seismicity indicators. A model simulation of intrusive rainfall arisen in South Atlantic Zone was developed in [65], where different simulation responses were analyzed for the precipitation rainfall field. The rainfall was parameterized and the FA was used for searching the optimal values of weights. The ABC algorithm was used in [66] for searching the optimal values of parameters MLP training on time series data prediction. In seismic hazard analysis, three parameters are important, i.e. peak ground acceleration (PGA), peak ground velocity (PGV), and peak ground displacement (PGD) [67], [68].

Acceleration is the rate of ground velocity change (measured in g, where g=980 cm/s^2), velocity refers to the rate of ground motion (measured in cm/s), and displacement to the distance that a particle is removed from it at rest position [8]. However, the peak values refer to the maximum values of the mentioned values.

V. Future Directions

Soft computing techniques are intended to complement each other [69]. Some of them can be combined, or one technique can be used when the other failed to meet the objectives of the study. In addition, by opportunities that offered by fuzzy logic, artificial neural networks and genetic algorithms, it becomes more feasible to attack harder and larger problems [70].

Earthquake prediction from data analysis and further improvement of both the design outcome and the design process, are such hard problems in earthquake engineering. The applicability of soft computing techniques in civil engineering has been significant in very past years [71]. However, in earthquake engineering field, in the present situation, the research and development of soft computing is only just starting, so far failing to play its proper role [72]. By considering the efficiency of soft computing methods in solving varieties of engineering problems and the fact that these methods are not yet mature, thus soft computing methods are expected to gain more research interest.

VI. Conclusion

In this paper, firstly taxonomy of the problems arisen in earthquake engineering that are appropriate for solving with soft computing techniques include optimal seismic design of structures and earthquake prediction from data analysis, are discussed in more detail. Then, soft computing algorithms such as evolutionary algorithms, swarm intelligence and artificial neural networks are exposed. Finally, all aspects of applications of the soft computing algorithms in earthquake engineering are analyzed. Predict seismic location and earthquake magnitude, earthquake modeling/simulation, generation of THA sequences, prediction of parameters PGA, PGV, and PGD during the ground motion are such applications of the soft computing methods in earthquake engineering.

Despite of the fact that the soft computing techniques are very effective when it is applied to real-world problems that are not able to be solved by traditional hard computing, these techniques in earthquake engineering field applications and development trend are still in its infancy. On the basis of the above mentioned remarks, the authors believe that soft computing methods in earthquake engineering field will have a broad prospect.

References

[1] A. Elnashai, L. Sarno, Fundamentals of Earthquake Engineering (Wiley, 2010).

[2] R. Day, Geotechnical Earthquake Engineering (MacGraw-Hill, 2012).

[3] V. Gioncu, F. Mazzolani, Earthquake Engineering for Structural Design (CRC Press, 2010).

[4] A.E. Eiben, J.E. Smith, Introduction to Evolutionary Computing (Springer-Verlag, Berlin, 2003).

[5] C. Blum, D. Merkle, Swarm Intelligence(Springer-Verlag, Berlin, 2008).

[6] M. Hassoun, Fundamentals of Artificial Neural Networks, A Bradford Book, 2003.

[7] Earthquake Engineering Research 1982, Committee on Earthquake Engineering, Research Commission on Engineering and Technical Systems, National Research Council, National Academy Press, Washington, D.C. 1982.

[8] C. Arnold, R. Reitherman, Building Configuration and Seismic Design (John Wiley, New York, 1982).

[9] A. Preumont, Vibration Control of Active Structures: An Introduction (Springer-Verlag, Berlin, 2011).

[10] R. Guclu, H. Yazici, Fuzzy Logic Control of a Non-linear Structural System against Earthquake Induced Vibration, Journal of Vibration and Control, vol. 13, n. 11, 2007, pp. 1535-1551.

[11] M. D. Symans, F. A. Charney, A. S. Whittaker, M. C. Constantinou, C. A. Kircher, M. W. Johnson, and R. J. McNamara, Energy Dissipation Systems for Seismic Applications: Current Practice and Recent Developments", Journal of Structural Engineering vol. 134, n. 1, 2008, pp. 3-21

[12] H. Shayeghi, H. Eimani Kalasar, H. Shayanfar, and A. Shayeghi, PSO based TMD design for vibration control of tall building structures, in Proceedings of the International Conference on Artificial Intelligence (ICAI '09), 2009.

[13] N. R.Fisco and H. Adeli, Smart structures: Part I – Active and semi-active control. Scientia Iranica, vol.18, 2011, 275–284.

[14] S. Thenozhi, W.Yu,Advances in modeling and vibration control of building structures, Annual Reviews in Control, Elsevier, vol.37, 2013, pp.346–364.

[15] R. L. Mayes, F.Naeim, Design of Structures with Seismic Isolation,chapter 14, pp. 723-756.

[16] J. C. Ramallo1, E. A. Johnson, and B. F. Spencer Jr., ‘‘Smart’’ Base Isolation Systems, Journal of Engineering Mechanics, vol. 128, n. 10, 2002, pp. 1088–1099.

[17] O. E. Ozbulut and S. Hurlebaus, Fuzzy control of piezoelectric friction dampers for seismic protection of smart base isolated buildings, Bulletin of Earthquake Engineering, vol. 8, n. 6, 2010, pp. 1435– 1455.

[18] T.T. Soong, B.F. Spencer Jr, Supplemental energy dissipation: state-of-the-art and state-of-the practice, Engineering Structures, Elsevier, vol.24, 2002, pp. 243–259.

[19] T. T.Soong, A. M.Reinhorn, Y. P.Wang, and R. C.Lin, Full-scale implementation of active control-I: Design and simulation. Journal of Structural Engineering, 1991, pp.3516–3536.

[20] A. Schmidt, The Design of an Active Structural Vibration Reduction System Using a Modified Particle Swarm Optimization, 2010.

[21] R. Guclu and H. Yazici, “Vibration control of a structure with ATMD against earthquake using fuzzy logic controllers,” Journal of Sound and Vibration, vol. 318, n. 1-2, 2008, pp. 36–49.

[22] R.J. Geller, Earthquake prediction: a critical review, Geophys. J. Int., vol. 131, 1997, pp. 425-450.

[23] L.A. Zadeh, Foreword, Proceedings of the Second International Conference on Fuzzy Logic and Neural Networks, Iizouka, Yapan, 1992, pp. XIII-XIV.

[24] D.K. Pratihar, Soft Computing: Fundamentals and Applications, (Alpha Science International Ltd., Oxford, 2014).

[25] C. Darwin, On the Origin of Species(Harvard University Press,London, 1859).

[26] D. Goldberg, Genetic Algorithms in Search, Optimization, and Machine Learning (Addison-Wesley, Massachusetts, 1996).

[27] J. Koza, Genetic Programming 2 - Automatic Discovery of Reusable Programs (MIT Press, Cambridge, USA, 1994).

[28] T. Bäck, Evolutionary Algorithms in Theory and Practice - Evolution Strategies, Evolutionary Programming, Genetic Algorithms(University Press, Oxford, 1996).

[29] L. Fogel, A. Owens, M. Walsh, Artificial Intelligence through Simulated Evolution(John Willey, New York, US, 1966).

[30] R. Storn, K. Price, Differential Evolution: A Simple and Efficient Heuristic for Global Optimization over Continuous Spaces. Journal of Global Optimization, vol. 11 no. 4, 1997, pp. 341-359.

[31] J. Kennedy, R. Eberhart, The Particle Swarm Optimization; Social Adaptation in Information Processing. In D. Corne, M. Dorigo, F.

Glover, New Ideas in Optimization, McGraw Hill, London, UK,1999, pp. 379-387.
[32] D. Karaboga, B. Bastruk, A Powerful and Efficient Algorithm for Numerical Function Optimization: Artificial Bee Colony (ABC) Algorithm. Journal of Global Optimization, vol. 39 n. 3, 2007,pp. 459-471.
[33] X.-S. Yang, Firefly Algorithm. In X.-S. Yang, Nature-Inspired Metaheuristic Algorithms,Luniver Press, London, UK, 2008, pp. 79-90.
[34] I. Fister, I. Jr. Fister, X.-S. Yang, J. Brest, A comprehensive review of firefly algorithms, Swarm and Evolutionary Computation, vol. 13, 2013, pp. 34-46.
[35] Z.W.Geem, Recent Advances in Harmony Search Algorithm (Springer-Verlag, Berlin, 2012).
[36] M. Dorigo, G. Di Caro, The Ant Colony Optimization Meta-heuristic. In D. Corne, M. Dorigo, F. Glover, New Ideas in Optimization,McGraw Hill, London, UK, 1999,pp. 11-32.
[37] D. Rumelhart, J. McClelland, Parallel Distributed Processing (MIT Press, Cambridge, 1986).
[38] R.J. Williams, A learning algorithm for continually running fully recurrent neural networks, Neural Computation, MIT Press, vol. 1 n. 2, 2008, pp. 270-280.
[39] E. Wong, Stochastic Neural Networks, Algorithmica, Springer Berlin Heilderberg, vol. 6 n. 1-6, 1991, pp. 466-478.
[40] B. Happel, J. Murre, The Design and Evolution of Modular Network Architecture, Neural Networks, vol. 7, 1994, pp. 985-1004.
[41] P. Auer, H. Burgsteiner, W. Maass, A learning rule for very single universal approximators consisting of a single layer perceptrons, Neural Networks, vol. 21 n. 5, 2008, pp. 786-795.
[42] D.S. Brookmhead, D. Lowe, Multivariable functional interpolation and adaptive network, Complex Systems, vol. 2, 1988, pp. 321-355.
[43] T. Kohonen, Self-Organized Formulation of Topological Correct Feature Maps, Biological Cybernetics, vol. 43 n. 1, pp. 59-69.
[44] R. Hecht-Nielsen, Neurocomputer applications, Neural Computers, Springer Verlag, Berlin, Heidelberg, 1988, pp. 445-453.
[45] D.F. Specht, Probabilistic neural networks, Neural Networks, vol. 3 n. 1, 1990, pp. 109-118.
[46] S. Kirkpatrick, C.J. Gellat, M. Veechi, Optimization by Simulated Annealing. Science, vol. 220 n. 4578, 1983, pp. 671-680.
[47] C. Cortes, V.N. Vapnik, Support-Vector Networks, Machine Learning, Kluwer Academic Publisher, vol. 20 n. 3, 1995, pp. 273-297.
[48] T.K. Caugney, Nonlinear Theory of Random Vibrations, Advances in Applied Mechanics, Acadamic Press, vol. 11, 1971, pp. 209-253.
[49] T.K. Caugney, Equivalent Linearization Techniques, TheJournal of the Acoustical Society of America, California Institute of Technology, Pasadena, vol. 35 n. 11, 1963, pp. 1706-1711.
[50] K. Jármai, J. Farkas, Y. Kurobane,Optimum seismic design of a multi-storey steel frame, Engineering Structures, vol. 28 n. 7, 2006, pp. 1038 – 1048.
[51] AYT. Leung, H. Zhang, CC. Cheng, YY. Lee, Particle swarm optimization of TMD by non-stationary base excitation during earthquake, Earthquake Engineering & Structural Dynamics, Wiley Online Library, vol. 37 n. 9, 2008, pp. 1223 - 1246.
[52] S. Gholizadeh, E. Salajegheh,Optimal seismic design of steel structures by an efficient soft computing based algorithm,Journal of Constructional Steel Research, Elsevier, vol. 66 n. 1, 2010, pp. 85 – 95.
[53] SM. Seyedpoor, J. Salajegheh, E. Salajegheh, S. Gholizadeh, Optimal design of arch dams subjected to earthquake loading by a combination of simultaneous perturbation stochastic approximation and particle swarm algorithms, Applied Soft Computing, Elsevier, vol. 11 n. 1, 2011, pp. 39 – 48.
[54] N. Xiao, L. Su, Y. Wang, Utilization of Particle Swarm Optimization in Equivalent Linearization Method Applied to Earthquake Engineering,Advances in Structural Engineering, Multi-Science, vol. 14 n. 2, 2011, pp. 179 – 188.
[55] S. Gharehbaghia, M.J. Fadaee, Design Optimization of RC Frames under Earthquake Loads, Int. J. Optim. Civil Eng, vol. 2 n. 4, 2012, pp. 459 – 477.
[56] M. Khatibinia, M.J. Fadaee, J. Salajegheh, E, Salajegheh, Seismic reliability assessment of RC structures including soil-structure interaction using wavelet weighted least squares support vector machine,Reliability Engineering & System Safety, Elsevier, 2012.
[57] K. Ye, Z. Chen, H. Zhu, A proposed strategy for the application of the modified harmony search algorithm to code-based selection and scaling of ground motions,Journal of Computing in Civil Engineering, American Society of Civil Engineers, 2012.
[58] A.Kaveh, P. Zakian,Optimal design of steel frames under seismic loading using two meta-heuristic algorithms,Journal of Constructional Steel Research, Elsevier, vol. 82, 2013, pp. 111 – 130.
[59] M. Sonmez, E. Aydin, T. Karabork, Using an artificial bee colony algorithm for the optimal placement of viscous dampers in planar building frames,Structural and Multidisciplinary Optimization, Springer Berlin Heidelberg, vol. 48 n. 2, 2013, pp. 395 – 409.
[60] E. Salajegheh, S. Gholizadeh, M. Khatibinia, Optimal design of structures for earthquake loads by a hybrid RBF-BPSO method, Earthquake Engineering and Engineering Vibration, Springer Berlin Heidelberg, vol. 7 n. 1, 2008, pp. 13 – 24.
[61] S. Gholizadeh, E. Salajegheh, Optimal design of structures subjected to time history loading by swarm intelligence and an advanced metamodel, Computer Methods in Applied Mechanics and Engineering, Elsevier , vol. 198 n. 37, 2009, pp. 2936 – 2949.
[62] D. Han, G. Wang,Application of particle swarm optimization to seismic location,Genetic and Evolutionary Computing, 2009. WGEC'09. 3rd International Conference on, IEEE, 2009, pp. 641 – 644.
[63] K. Deep, A. Yadav, S. Kumar,Improving local and regional earthquake locations using an advance inversion Technique: Particle swarm optimization,World Journal of Modelling and Simulation,vol. 8 n. 2, 2012, pp. 135 – 141.
[64] H. Adeli, A. Panakkat, A probabilistic neural network for earthquake magnitude prediction, Neural Networks, Elsevier, vol. 22, 2009, pp. 1018 – 1024.
[65] A.F. Santos, H.F. Campos Velho, E.F.P. Luz, S.R, Freitas, G. Grell, M.A. Gan, Firefly optimization to determine the precipitation field on South America,Inverse Problems in Science and Engineering, Taylor & Francis, vol. 21, n. 3, 2013, pp. 451 – 466.
[66] H. Shah, R. Ghazali, N. Mohd Nawi, Using artificial bee colony algorithm for MLP training on earthquake time series data prediction,Journal of Computing, vol. 3 n. 6, 2011, pp. 135 – 142.
[67] A.H. Alavi, A.H. Gandomi, Prediction of principal ground-motion parameters using a hybrid method coupling artificial neural networks and simulated annealing, Computers & Structures, Elsevier, vol. 89 n. 23, 2011, pp. 2176 – 2194.
[68] A.H. Gandomi, A.H. Alavi, M. Mousavi, S.M. Tabatabaei, A hybrid computational approach to derive new ground-motion prediction equations, Engineering Applications of Artificial Intelligence, Elsevier, vol. 24 n. 4, 2011, pp. 717 – 732.
[69] Soft Computing, 2014, http://en.wikipedia.org/wiki/ Soft Computing.
[70] K.M. Saridakis, A.J. Dentsoras, Soft computing in engineering design – A review, Advanced Engineering Informatics, vol. 22, 2008, pp. 202–221.
[71] Subrata Chakraborty, Gautam Bhattacharya "Proceedings of the International Symposium on Engineering under Uncertainty"
[72] P. Lu, S. Chen, Y. Zheng, Artificial Intelligence in Civil Engineering, Mathematical Problems in Engineering Volume 2012, Article ID 145974, 22 pages

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