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Evolutionary polynomial regression based modelling of clay compressibility using an enhanced hybrid real-coded genetic algorithm

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ABSTRACT

A new approach for evaluating the compressibility of remoulded clays using the evolutionary polynomial regression (EPR) and optimization methods is proposed. An efficient hybrid real-coded genetic algorithm (RCGA) with a new hybrid strategy combined with a self-adaptive mutation is first developed. Then, the enhanced RCGA is applied to construct the EPR procedure for compression index. To highlight the performance of the RCGA in the proposed procedure, three other excellent optimization algorithms are selected and compared. All comparisons between predictions and measurements demonstrate that the EPR-based modelling of clay compressibility using the enhanced RCGA gives a more accurate and reliable correlation between the compression index and physical properties of remoulded clays.

1. Introduction

Over last decades, the soft computing techniques have been developed rapidly, and have been applied to different complicated engineering problems (Adeli, 2001; Rezania and Javadi, 2007; Rezania et al., 2008; Shahin, 2014). Among these techniques, the evolutionary polynomial regression (EPR) has been paid more attention due to its more powerful ability in searching the target expression than artificial neural networks (ANNs) and genetic programming (GP) (Rezania et al., 2010; Gurocak et al., 2012; Alemdag et al., 2016).

More recently, the EPR has been increasingly adopted in the field of geotechnical engineering and has been proved to be successful, such as the evaluation of liquefaction potential based on cone penetration test (CPT) results (Rezania et al., 2010), the assessment of earthquake-induced soil liquefaction and the lateral displacement (Rezania et al., 2011), the prediction of total sediment load of rivers (Adilah et al., 2012), modelling of permeability and compaction characteristics of soils (Ahangar-Asr et al., 2011; Gurocak and Alemdag, 2012; Alemdag, 2015), the evaluation of axial bearing capacity of piles (Alemdag et al., 2008; Ebrahimian and Movahed, 2013; Shahin, 2014), the prediction of uplift capacity of suction caissons (Rezania et al., 2008), modelling the soil behaviour and applying in the finite elements analysis (Faramarzi et al., 2012; Javadi et al., 2012; Faramarzi et al., 2013) and the prediction of the stability of soil and rock slopes (Gurocak et al., 2008; Ahangar-Asr et al., 2010; Alemdag et al., 2014). However, the application of EPR to evaluate the compressibility of soils has not been reported so far. Note that the compression index is extremely important in calculating the settlement of foundation, the high accuracy of the correlation formulation is needed. Thus, the EPR is recommended to improve current empirical equations for the clay compressibility.

The global search for the best form of the EPR equation is usually performed by means of a genetic algorithm (GA) over the values in the user defined vector of exponents. Thus, in order to improve the performance of EPR, a GA with high search ability for searching symbolic structures is necessary. The traditional GAs encoded as the binary strings were commonly used to conduct the search procedure in the EPR (Giustolisi and Savic, 2006). The performances of binary GAs are found to be satisfactory on small and moderate size problems requiring less precision in the solution. But for high dimensional problems in which high degree of precision is desired, binary GAs require huge computational time and memory (Goldberg, 1991; Deep and Thakur, 2007a, 2007b). To overcome these difficulties, real-coded GAs, in which the

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decision variables are encoded as real numbers, can be adopted. In the other words, real-coded GAs are superior to binary coded GAs for continuous optimization problems (Janikow and Michalewicz, 1991). However, this powerful tool has rarely been used to improve the performance of EPR. Thus, the EPR employing a high efficient RCGA to search the best form of target expression is highly advised.

Therefore, this paper aims to propose an efficient RCGA and apply to EPR procedure to improve the performance of modelling the compression index of clays. First, a hybrid RCGA is proposed involving three different outstanding crossover operators under a new hybrid strategy. A self-adaptive mutation is also adopted in the proposed RCGA to improve the search efficiency. Then, the new RCGA is applied to propose an efficient EPR procedure in modelling the compression index with physical properties of remoulded clays. Besides, three other excellent optimization algorithms are also respectively applied in EPR procedure for the same case to highlight the performance of the new RCGA in EPR.

2. Proposed new hybrid RCGA

2.1. Basic scope of proposed RCGA

Due to the good performance of RCGA on solving the continuous problems, a new enhanced RCGA was proposed to conduct the optimization in the EPR. The framework of the enhanced RCGA is shown in Fig. 1, where p_C, p_M and p_S are the probabilities at which children are produced by the crossover, mutation and simplex. The evolutionary of the proposed hybrid RCGA is similar to the GA proposed by Yamamoto and Inoue (1995). The main genetic operators used in the enhanced RCGA are selection, crossover, mutation and replacement. First, the tournament selection was implemented for selecting the individuals to the mating pool, which has been validated successfully in RCGAs (Arumugam et al., 2005; Mokhade and Kakde, 2014). In order to keep the diversity loss to the minimum, the tournament size was chosen as two in the proposed algorithm.

2.2. Adopted crossovers and new hybrid strategy

During the evolution process, three crossover operators are adaptively selected to generate the children according to the probability of crossover (p_C) and the probability of simplex (p_S), respectively. The Simulated Binary crossover (SBX) proposed by Deb and Agrawal (1995), the Blend crossover (BLX-α) developed by Eshelman and Schaffer (1992) and the Simplex crossover (SPX) developed by Da Ronco and Benini (2013) were adopted in the proposed RCGA, which are introduced in Appendix A in details. The probability to apply the SBX or BLX-α to selected parents is 50% after the selected parents satisfying the probability of crossover (p_C). The SBX and BLX-α are conventionally outstanding crossover operators, whose search ability has been highlighted by many researchers (Eshelman and Schaffer, 1992; Deb and Agrawal, 1995; Eshelman, 1997) in the optimization field. According to Da Ronco and Benini (2013), the SPX has good performance on functions with multimodality and/or epistasis. This also indicates that the SPX can enhance the search ability of the algorithm due to its exploration and exploitation characteristics. Therefore, the search ability of the new RCGA can be guaranteed by combining the advantages of these crossover operators.

2.3. Mutation

In order to prevent the population convergence to a suboptimal solution, the mutation operator is also necessary for the GA. Since the mutation serves as a process to change the gene of a chromosome randomly, it is able to keep the diversity of the population which is important in finding the global optimum value. A newly developed and well performed mutation operator, named Dynamic Random Mutation (DRM) proposed by Chuang et al. (2015) was adopted in the proposed RCGA to perform the mutation based on the probability of mutation (p_M). The rules of DRM are shown in Appendix A. The DRM mutation is a self-adaptive operator, which could improve the search efficiency of the proposed RCGA.

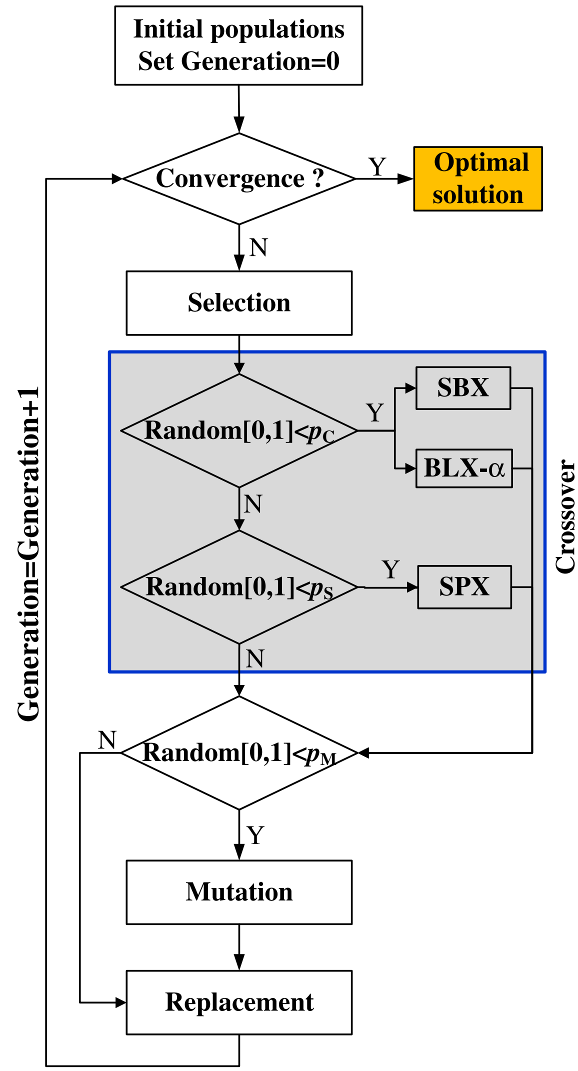

Fig. 1. Flow chart for the proposed real-coded genetic algorithm.

2.4. Replacement

Since the population size is kept constant, the survivor selection for both parent and offspring populations is critical to preserve the current best found solution for the subsequent evolution. Thus, the elitism strategy in NSGA-II proposed by Deb et al. (2002) was implemented in the new RCGA to perform the replacement process, which allows the competition between the parent and offspring after crossover and mutation processes to survive better solutions.

3. EPR procedure using RCGA

The evolutionary polynomial regression (EPR) is a data-driven method based on evolutionary computing, aimed to search for polynomial structures representing a system, which was first introduced by Giustolisi and Savic (2006) with applications in the hydroinformatics