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A Novel Multiobjective Optimization for Cement Stabilized Soft Soil based on Artificial Bee Colony

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ABSTRACT

Cement is the most widely used additive in soft soil stabilization due to its high strength and availability. The cement content and curing time have a direct influence on the stabilization cost and hence it is prudent to minimize these variables to achieve optimality. Thus, it is a classical multi-objective optimization problem to find the optimum combination of cement content used and the curing time provided to achieve the target strength. This paper brings out the use of Vector Evaluated Artificial Bee Colony (VEABC) algorithm, a multi-objective variant of Artificial Bee Colony (ABC) technique, for the problem on hand. VEABC is a swarm intelligence algorithm, which employs multiple swarms to handle the multiple objectives and the information migration between these swarms ensures a global optimum solution is reached. Due to the stochastic nature of ABC algorithm, the resulting Pareto Curve will cover a good range of data with smooth transition. The Pareto fronts obtained for target strength could be used as calibration charts for scheduling the soft soil stabilization activities.

KEYWORDS

Artificial Bee Colony (ABC), Calibration Charts, Cement Stabilization, Multi-Objective Optimization, Swarm Intelligence, Vector Evaluated Artificial Bee Colony (VEABC)

1. INTRODUCTION

Soft soil engineering is often challenging to geotechnical engineers. The Chek Lap Kok International Airport at Hong Kong (Zhu et al., 2001), Surnabhumi International Airport at Thailand (Moh et al., 2003) and Trans-Tokyo Bay Highway Project of Japan (Tatsuoka et al., 1997) are some of the examples of massive infrastructure projects constructed on soft soils. Soft soils are wide spread and cover many regions of the world such as Japan, Eastern Canada, Norway, Sweden and other Scandinavian countries, India and the South East Asian countries. Inadequate strength of soft soils is a serious constraint to take up any developmental activity on soft soils. The strength and stiffness of soft ground are often improved by cement stabilization. The extent of the strength improvement of soft soil depends on physico-chemical factors such as the type of the stabilizing agent, the type of soil, the type and content of organic matter, the water content, the curing period and the curing conditions (Horpibulsuk, 2001; Horpibulsuk, Bergado, & Lorenzo, 2003; Miura, Horpibussuk, & Nagaraj, 2001; Narendra, Sivapullaiah, Suresh, & Omkar, 2006; Narendra, 2006; Porbaha, 1998; Suzuki, Fujimoto, & Taguchi, 2014; Tan, Goh, & Yong, 2002; Uddin, Balasubramaniam, & Bergado, 1997; Yin and

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Lai, 1998). Advanced cement stabilization techniques such as deep mixing (Tan, Goh, & Yong, 2002) have been developed, and widely used for improving the strength of soft grounds. In deep mixing, the cement grout or dry cement is injected into the natural soil at the depth required and a blade is pushed into the ground to mix the soil and cement (Porbaha, 1998; Tan, Goh, & Yong, 2002). This technique has become quite common and presently many countries have their deign guides for practice.

In the cement stabilization of soft soil, the cement content used and the curing period involved has a direct effect on the cost of the project. Hence, the cement stabilization of soft soil could be viewed as an optimization problem, with the objective to find the optimum combination of cement content to be used and the curing time to be provided to achieve the required soil strength. Since, both cement content and curing time has a direct effect on the total cost incurred, one has to minimize both cement content and the curing time to ensure optimality. The two objectives; minimizing cement content and minimizing curing time are both conflicting. So this becomes a classical multi-objective optimization problem with competing objectives.

In case of a multi-objective optimization problem with conflicting objective, instead of a single optimal solution that satisfies all the objectives, a number of solutions, which indicate the trade-off between the multiple objectives, exist. Hence the concept of *Pareto* optimality (Schaffer, 1984; Eckart, Marco, & Stefan, 2004) is introduced. A *Pareto Front* (Eckart, Marco, & Stefan, 2004) gives a set of optimal solutions, for a given set of conflicting objectives. A typical *Pareto Front* is shown in Figure 1, where the solid line represents the *Pareto Front* and the symbols represent all the feasible solutions (both optimal and non optimal). The *Pareto Fronts* obtained, in the present case, which is cement content versus curing period for a given target strength could be used as calibration charts or a ready reference for scheduling the cement stabilization activities.

Conventionally, there are a number of gradient based methods available for identifying the *Pareto* optimal solutions (Jorge & Stephen, 2000). The nature of the current problem with its vast solution space and conflicting variables makes it combinatorially explosive, rendering it as a challenge for conventional gradient based methods. The traditional gradient based methods are good at accurate and exact computation but are known to have brittle operations when faced with combinatorially explosive problems (Deb, 2001). Hence the problem on hand warrants the use of modern non-parametric swarm intelligence methods. These swarm intelligence methods with their stochastic means are well equipped to handle such combinatorially explosive problems (Omkar, Mudigere, Narayana Naik, & Gopalakrishna, 2008; Omkar et. al., 2009; Omkar et. al., 2011b; Parsopoulos et al., 2004; Qie & Wang, 2007; Swagatam & Amit, 2007).

In the current work an attempt has been made to use the Artificial Bee Colony (ABC) (Akbari, Hedayatzadeh, Ziarati, & Hassanizadeh, 2012; Alvarado-Iniesta, Garcia-Alcaraz, Rodriguez-Borbon, & Maldonado, 2013; Karaboga & Basturk, 2008; Omkar et. al., 2011b) for the cement stabilization optimization. The ABC is a relatively new swarm intelligence optimization technique (Akbari, Hedayatzadeh, Ziarati, & Hassanizadeh, 2012; Andries, 2005; Vitorino, Ribeiro, & Bastos-Filho, 2015) which, due to its stochastic nature, results in a *Pareto Curve,* covering a good range of data with smooth transition. Swarm intelligence algorithms are a new range of computational algorithms that have emerged from the behaviour of social insects. Social insects are usually characterized by their self-organization and the absence of central control. Still, complex group behaviour emerges from the interactions of individuals who exhibit simple behaviours by themselves. In social insects, every individual is autonomous. They can only obtain local information, and interact with their geographical neighbours. All these features characterize swarm intelligence. Examples of systems like this can be found in nature, including bee colonies, ant colonies, bird flocking, animal herding, fish schooling etc. Inspired by the bee behaviour, Artificial Bee Colony (ABC) (Basu, 2011; Karaboga & Basturk, 2008; Nikolić, & Teodorović, 2013; Omkar et. al., 2011b; Vitorino, Ribeiro, & Bastos-Filho, 2015) is one of the generally applicable techniques used for optimizing numerical functions and real-world

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