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Identifying parameters of easily crushable sand and application to offshore pile driving

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ABSTRACT

The estimation of the bearing capacity of driven piles of offshore platform in easily crushable sand is a big issue due to the difficulty of parameter identification. The paper proposes an efficient optimization procedure for identifying parameters of easily crushable sand which is then applied to the pile driving simulation. The Nelder-Mead Simplex genetic algorithm (NMGA) is first proposed and a newly enhanced elasto-plastic breakage model is adopted. Then, the performance of NMGA is validated by identifying parameters from synthetic tests, and further verified by triaxial tests on limestone grains, based on which the necessary number of objective tests are also suggested. Finally, the proposed procedure is applied to identify parameters of carbonate marine sand, and the Coupled Eulerian Lagrangian based large deformation analysis combined with the breakage model is carried out for pile driving in the same sand. The role of grain breakage in bearing capacity of driven pile is also discussed. All comparisons demonstrate that the proposed NMGA with breakage model based parameter identification procedure is efficient and effective for easily crushable sand, and the established large deformation analysis of pile driving using the identified parameters is applicable in estimating the bearing capacity.

1. Introduction

Foundations of offshore platforms are in the majority of cases piled-based, which are the most common foundation system due to their lower cost and simplicity and mainly driven to a certain design depth using hammers (Randolph et al., 2005). The most common problems for driven piles are associated with insufficient capacity (as indicated by driving performance or dynamic monitoring) at the end of driving. The capacity of driven piles in sands was identified by Randolph et al. (1994) as being the "area of greatest uncertainty in foundation design".

During the process of pile driven, grain breakage commonly occurs when sand undergoes compression and shearing, especially for sand with low Mohr's hardness mineral (e.g. Gypsum, Calcite and Fluorite with Mohr's hardness less than 4) even under very low confining stress, which is defined as "easily crushable sand" in this paper. From a different viewpoint, Zhang et al. (2016) used fracture mechanics and energy arguments to demonstrate the equivalence between measures of crushability based on yielding stress and measures of crushability based on energy input and dissipation. In either case, it is the fracture properties of the grain-forming mineral that controls the macroscopic crushability. More recently, it was shown that such link between macroscopic crushability and grain-scale fracture can be used to develop constitutive models at continuum scale (Zhang and Buscarnera, 2017).

The impact of grain breakage on the mechanical behavior of granular materials has been highlighted in the past decades (Coop, 1990; Coop et al., 2004; Lo and RoY, 1973; Miao and Airey, 2013). In order to describe the effect of grain breakage, numerous constitutive methods considering the grain breakage have been developed (Cecconi et al., 2002; Chen et al., 2015; Daouadji et al., 2001; Einav, 2007; Hu et al., 2011; Kong et al., 2017; Liu and Gao, 2016; Russell and Khalili, 2004; Xiao and Liu, 2016; Yao et al., 2008a; Yin et al., 2016). Especially in advanced breakage models incorporating the critical state concept, additional parameters are introduced which are difficult to be determined by conventional laboratory or field tests. Especially in advanced breakage models incorporating the critical state concept, additional parameters are introduced which are difficult to be determined by conventional laboratory or field tests. For instance, in critical state based breakage models, the critical state line kinematically moves with the amount of grain crushed. Thus, the critical state related parameters, the hardening parameters and the dilatancy parameters become much more

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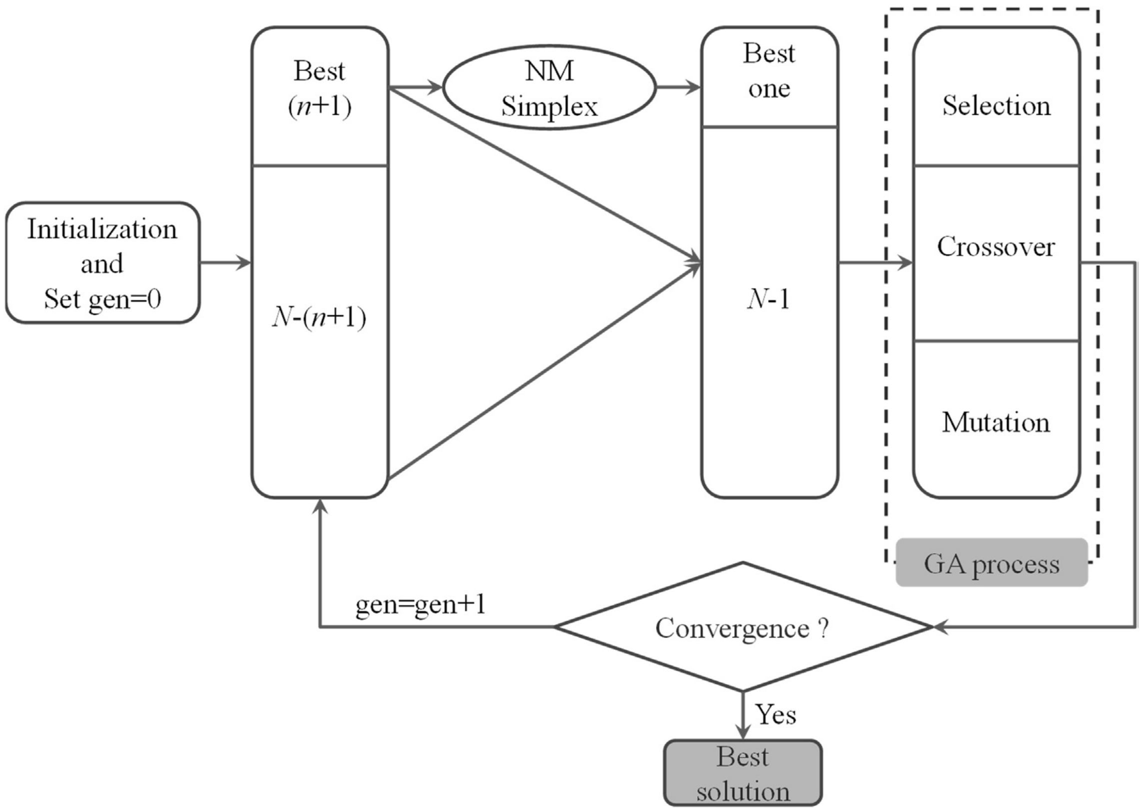

Fig. 1. Flow chart of the NMGA.

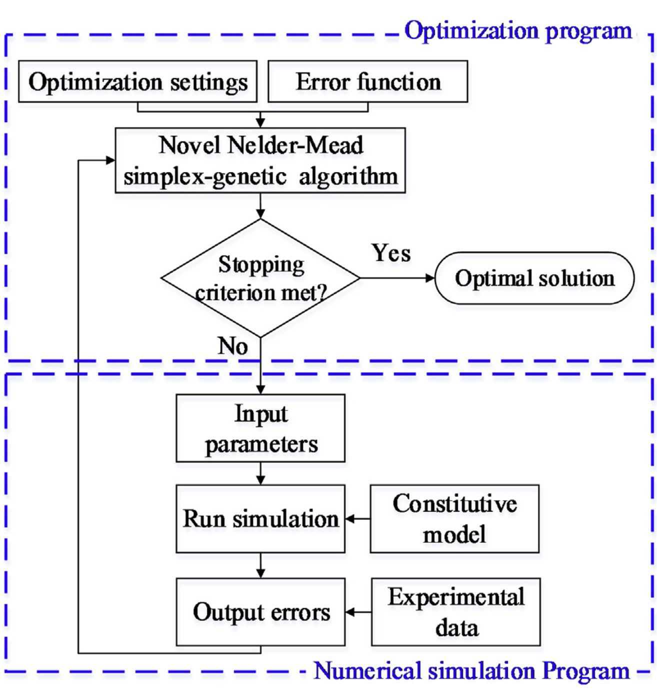

Fig. 2. Proposed mono-objective optimization procedure.

difficult to be calibrated in breakage model than in conventional critical state based models, such as the critical state line related parameters (e.g., v_f and λ_f) in the model of Russell and Khalili (2004); the critical state parameters (e_{ref0} and λ) in the model of Hu et al. (2011); the critical state parameters ($e_{\Gamma i}$, ϕ_{cr}, and λ), the dilatancy parameters (k_d and A) and the hardening parameters (ξ_{L0}, ξ_L, ξ_U, and γ) in the model of Chen et al. (2015); the critical state related parameters (λ, e_{B0}, k_e, and χ_B) and two dilatancy constants (d_0 and k_d) in the model of Xiao and Liu (2016). This difficulty is much more pronounced for very easily crushable sand, and poses a challenge in terms of engineering practice. As a consequence, the breakage models were seldom used in the engineering practice. To improve the determination of parameters, more laboratory tests are becoming necessary, which results in a relatively high experimental cost. Therefore, an efficient approach to identify model parameters by a cost-saving way is useful and will be attractive for engineering practice.

Recently, the optimization method based on genetic algorithm (GA) has been applied successfully in the geotechnical engineering since its application can reduce the cost of laboratory testing or in situ monitoring. For example, the parameter identifications of various constitutive models for different soils have been carried out using optimizations with GA (Jin et al., 2016b, 2017a, 2017b, 2017c; Levasseur et al., 2008; Pal et al., 1996; Papon et al., 2012; Rokonuzzaman and Sakai, 2010; Samarajiva et al., 2005; Ye et al., 2016; Yin et al., 2018, 2017). Along this way, it will be attractive if this powerful tool can be applied to identify parameters of breakage models for easily crushable sand.

Therefore, this study aims to propose an efficient optimization procedure for identifying parameters of easily crushable sand based on conventional laboratory tests which is then applied to the pile driving simulation. For this purpose, a recently enhanced elasto-plastic breakage model is adopted for simulations. A novel Nelder-Mead Simplex enhanced genetic algorithm (NMGA) is developed to minimize the error function during the optimization process. Then, the parameter identification using three synthetic drained triaxial tests generated by the adopted model as objective tests is conducted to evaluate the performance of NMGA. After that, the model parameters for limestone grains are identified using the proposed optimization procedure with discussions on the necessary number of objective tests. Finally, the proposed procedure is applied to identify parameters of Dog's bay sand using four triaxial tests and validated by three other triaxial tests. The Coupled Eulerian Lagrangian based large deformation finite element analysis

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