Computers and Geotechnics 78 (2016) 38–53

Contents lists available at ScienceDirect

Computers and Geotechnics

journal homepage: www.elsevier.com/locate/compgeo

Research Paper

Comparison of Press-Replace Method and Material Point Method for analysis of jacked piles

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ARTICLE INFO

Article history:
Received 30 May 2015
Received in revised form 27 April 2016
Accepted 28 April 2016

Keywords:
Jacked piles
Sand
Numerical analysis
Press-Replace method
Material Point Method

ABSTRACT

In this study, installation of jacked piles in sand is simulated using Press-Replace Method (PRM) and Material Point Method (MPM) and the results are compared together. This comparison is important because a realistic and yet efficient simulation of installation of jacked piles is an appealing step towards the design and analysis of this type of displacement piles. It is shown that PRM as a method that is founded on small-strain finite element method can produce pile and soil responses that are in a promising agreement with those of MPM which is a finite-deformation analysis method.

1. introduction

Pile installation using dynamic driving methods is associated with undesirable environmental effects such as noise, vibration and pollution. Therefore, pile jacking (pressing) has become attractive due to the environmental advantages that it has over conventional driving methods [1]. In addition to the environmental advantages, it is possible to estimate the ultimate load capacity of jacked piles during pile installation based on the measured jacking load [2]. Jacked piles, in their initial application, were mainly used to underpin existing foundations to increase their capacity and decrease their settlement [3]. Nowadays, there is an increasing trend in using jacked piles as foundations of new structures, in particular, in urban environment where minimizing the noise and vibration due to construction activities is desirable. Due to the tendency in using jacked piles, many researchers have studied jacked piles using experimental [2,4–10] and computational methods [1,11–13]. Furthermore, the simulation of jacked pile installation is a necessary and beneficial step towards simulating the installation of driven piles.

Realistic simulation of the installation process is a key step in analyzing the behavior of jacked piles. In the past years, number of researchers have focused on simulating the whole installation process using large-deformation numerical analysis methods such as Arbitrary Eulerian–Lagrangian (AEL) method [14,15] and its derivation, namely, Coupled Eulerian–Lagrangian (CEL) method [16,17], adaptive remeshing technique [11], and most recently Material Point Method (MPM) [18,19]. Besides finite-deformation analysis methods, a simpler method entitled Press-Replace Method (PRM) has been successfully used for simulation of jacked pile installation using small-deformation theory [20,21].

MPM has recently gained attentions in simulating large-deformation boundary and initial value problems in geotechnical engineering. Despite its promising performance, MPM is computationally expensive and relatively complicated which decrease its attraction for practice engineers who look for practical and straight-forward methods in a daily engineering practice. PRM, on the other hand, is a simple method that is based on small-deformation theory, which has been used solely for simulation of penetration problems such as pile jacking and cone penetration. The simplicity of PRM enables an engineer to model the installation process of jacked piles as a staged construction process by any finite element code. The purpose of this study is to compare PRM and MPM for numerical simulation of jacked piles during installation and operation. Such a comparison shows if the PRM can be relied upon for the analysis of jacked piles. It also reveals

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http://dx.doi.org/10.1016/j.compgeo.2016.04.017
0266-352X/

Nomenclature

α	hypoplasticity parameter that determines the dependency of peak friction angle with respect to the relative density	G	soil shear modulus
β	hypoplasticity parameter that determines the dependency of soil stiffness with respect to the relative density	G_i	interface shear stiffness
B	pile diameter	γ_d	soil dry unit weight
B_R	intergranular strain parameter of the hypoplastic model	h_s	granular hardness, determines the inclination of the void ratio limits in the hypoplastic model
C_c	coefficient of curvature	K_0	coefficient of lateral earth pressure at rest
C_u	coefficient of uniformity	L	pile length
D_{50}	mean particle diameter	m_R	intergranular strain parameter of the hypoplastic model
D_R	relative density	m_T	intergranular strain parameter of the hypoplastic model
δ_c	critical-state interface friction angle	n	hypoplasticity parameter that determines the curvature of the void ratio limits
δ	interface friction angle	Q_{sL}	limit shaft capacity
e	void ratio	r	radial distance from the pile center
e_{max}	maximum void ratio	R_i	interface reduction factor
e_{min}	minimum void ratio	R_{max}	intergranular strain parameter of the hypoplastic model
e_{d0}	minimum reference void ratio in the hypoplastic model	σ_{rr}	radial stress
e_{c0}	reference void ratio at the critical state in the hypoplastic model	σ_{zz}	vertical stress
e_{i0}	maximum reference void ratio in the hypoplastic model	σ_{rz}	shear stress
E_p	Young's modulus of the pile material	t_s	thickness of soil slices in the PRM analyses
$E_{oed,i}$	interface oedometric stiffness	u_r	radial displacement
ϕ	soil friction angle	u_z	vertical displacement
ϕ_c	critical-state friction angle	ν	soil Poisson's ratio
ϕ_p	peak friction angle	ν_i	interface Poisson's ratio
G_s	specific gravity	w	pile head settlement
		χ	intergranular strain parameter of the hypoplastic model
		ψ	soil dilatancy angle
		z	depth

the differences that exist between PRM and a more sophisticated method of pile installation simulation, namely MPM. For simplicity, this paper only focuses on the single-stroke jacking as an initial step in simulating the multi-stroke jacking of piles.

2. Analysis methods

2.1. Material Point Method

The Material Point Method (MPM) can be viewed as an extension of the Particle-In-Cell method (PIC) and was initially applied to fluid dynamic problem by Harlow [22]. Later on, Brackbill and his co-workers [23] developed the so-called fluid-implicit particle (FLIP) method, that is a PIC formulation, in which the particles carry all physical properties of the continuum. FLIP uses adaptive meshing which is able to model complex geometries and achieves better accuracy than does PIC. In 1994, the FLIP method was extended to adapt into solid mechanics by Sulsky et al. [24]. In the extended method, the weak formulation and the discrete equation are consistent with the finite element method (FEM). Furthermore, the constitutive equation is applied at each single particle, which allows the method to handle the history-dependent material behavior. In

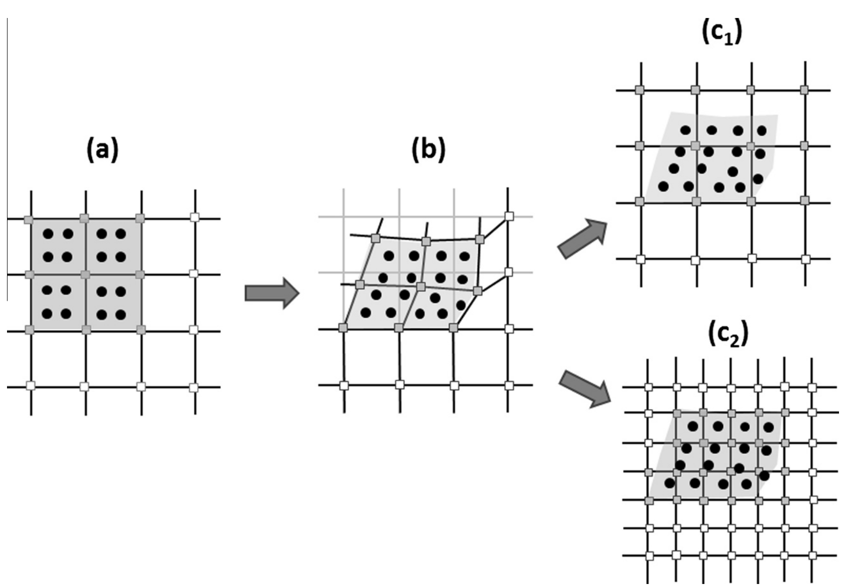

Fig. 1. The MPM solution algorithm: (a) initialization step, (b) incremental deformation (Lagrangian step) and (c_1) resetting the mesh or (c_2) redefining a new mesh (convective step).