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Finite Difference Time Domain Simulations of Dynamic Response of Thin Multilayer Soil in Continuous Compaction Control

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Abstract
For about 50 years, Continuous Compaction Control (CCC) has been somewhat applied in earthworks by using a roller integrated measurement during compaction process. In recent years, many researchers have developed a theoretical background of roller/soil interaction coupled to experimental verification. Basically theoretical parts of these research works have been performed using spring-dashpot dynamic models. By means of solutions of single degree of freedom equations in real time engineers are able to estimate the soil degree of compaction via reaction soil force. A major goal in this field of applied research is to find out if the desirable material density, the roller-integrated stiffness-measurement, and the in-situ elastic parameters of compacted materials could have a consistent relation. Regarding this, many previous studies were focused on earth fills with significant height. Due to this, the equipment measurement involved only one material. This work presents the results of numerical simulations using the Finite-Differences Time Domain method, in order to depict the response of thin multilayer systems when CCC is used. Numerical simulations are performed by using different height lifts. Toward to validate the models, synthetic time-stress diagrams are confronted with field measurement data reported in literature showing good agreement. Results show the dependency of vertical acceleration of drum-soil contact surface on the thick and the stiffness of the layers, and that the higher elastic moduli of the layered-system the lower acceleration of the roller when vibration forces still allow for continuous contact of drum and soil interface.

Keywords: Finite Differences, Soil Dynamics, Intelligent Compaction, Earthworks

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1 Introduction

In the middle 60´s many investigations concerning on compaction of soils were performed. The early work of D'Appolonia shows the interest of engineering community on the assessment of compaction degree of soils by using roller-integrated devices (D'Appolonia & Whitman, 1969). This pioneer experimental work involved spotted measurements of density of soil and vertical/horizontal stresses within soil mass. All measures were performed at an initial loose state, and during and after compaction activity. The optimal degree of compaction were study by varying roller size, roller operating frequency, forward speed, lift height, and number of roller passes. The author concluded that the number of roller passes is related with the degree and depth of compaction and that the higher operation frequency is applied the more density is reached. Recently works have performed several field investigation and dynamic analysis using lumped systems (Rinehart & Mooney, 2009) (Mooney & Rinehart, 2007), in order to assess field measurement of soil force reaction, depth of drum loads influence, compaction level, and stress distribution. These analyses were conducted by changing machine parameters as frequency operation, vibrational load, and moving velocity.

Besides these field investigations, numerical studies have been also performed. In the 80's and 90's, several studies were conducted in order to simulate numerically the compaction activity. These studies were performed using spring-mass systems of one, two or more degree of freedoms. Since then, engineers were able to estimate soil reaction by measuring the acceleration of the drum and solving the dynamic lumped equation. Analyses of the drum-soil forces allow researchers to evaluate compaction degree by several ways (Mooney & Adam, 2007). Indeed, complex simulations including hardening plasticity soil, several masses, and damping, were published (Pietzsch, 1991). More recently, it has been demonstrated that simpler lumped systems are enough for good accuracy with field tests (Anderegg & Kaufmann, 2004). Nowadays, 2D and 3D FEM simulations have been implemented. Some of them include not only soil complex constitutive models but also an elastic roller in order to solve the contact interaction problem and soil hysteresis (Erdmann & Adam, 2014). As well, there are several FEM studies which have used commercial software as LS-DYNA and ABAQUS in order to perform analysis of soil-drum interactions (Kim & Briaud, 2010) (Capraru, et al., 2014). All these efforts, their findings and also the necessity of perform real-time quality control and reliable quality assurance documentation; have encouraged companies and researchers to standardize the implementation of CCC on professional practice (Adam, 2007).

In these work we show the results of 2D numerical simulations of multiple thin layered soil mases subjected to vibratory loads using Finite Difference Time Domain method (FDTD) in order to integrate equation of motion. With regard to take into account inelasticity we use attenuation coefficients for compressional and shear material velocities and memory variables within the numerical scheme. For sake of simplicity we do not incorporate drum inertia and only simulate the case of full contact between drum and soil. Contact problem is approximated with geometrical Hertz solution. Explicit finite differences simulations have good agreement with field tests reported in literature. In the case of multi-thin-layered system simulation shows that stress waves spread out in a different manner than a single layer system. Moreover, acceleration of the drum for an operational frequency of 30 Hz shoes a decreasing relation with the rigidity of the layered system.

2 Finite-Difference Time Domain Scheme

For the porpoise of performing numerical simulations, authors wrote a code in Fortran 90 using FDTD expressions to integrate explicitly the equation of motion. Explicit Finite Differences is a useful integration technique due to its simpler implementation as a computer code. Using OpenMP directives we obtain important economizing of time. For example, in a serial code one simulation took almost 5 days. But using parallel programing computation with 3 threads computations required only 10 hours.