Proceedings Index

EM2004

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June 13-16, 2004

Author Index

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System Identification I
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Experimental Study of Moving Force Identification on a Continuous Bridge.

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Experimental Study of Moving force Identification on a Continuous Bridge.

Tommy H.T. Chan and Demeke B.Ashebo

Abstract

This paper describes an experimental study on the identification of moving vehicle axle loads on a continuous supported bridge based on the measured bending moment responses. A bridge-vehicle system model was fabricated in the laboratory. The bridge was modeled as a three span continuous supported beam and the vehicle was modeled as a vehicle model with two-axle loads. A number of strain gauges were adhered to the bottom surface of the beam to measure the bending moment responses. Using measured bending moment responses as an input, the inverse problem was solved to identify moving loads. The moving forces were identified when considering bending moment responses from all spans of the beam and only one span respectively. The rebuilt responses were reconstructed from the identified loads as a forward problem. To study the accuracy of the method the relative percentage errors were calculated with respect to the measured and the rebuilt bending moment responses. The rebuilt bending moment responses obtained from the identified forces are in good agreement with measured bending moment responses. This indirectly shows that the method is capable of identifying moving loads on continuous supported bridges.

Computational Poromechanics
June 16, 2004
15:30
Clayton 124
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Acoustic Behavior of a Poroelastic Mindlin Plate

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The numerical treatment of noise insulation of solid walls has been an object of scientific research for many years. The main noise source is the bending vibration of the walls modeled by plate theory. In generally, walls consist of porous material, for instance concrete or bricks. To model the effects of the porous structure more realistic it is advantageous to formulate a plate theory based on poroelastic constitutive equations.

A theory for poroelastic Kirchhoff plates was presented by Beskos and Theodorakoupoulos. It is well known that for the approximation of the behavior of thin plates, where shear deformation and rotatory inertia can be neglected, this theory is very useful. However, if the structure under consideration becomes thicker, e.g., a wall, the refined theory of Reissner/Mindlin is required.

The most common used theory of dynamic poroelasticity was developed by Biot formulated either using the solid and fluid displacements as unknowns or, more physically motivated, using the solid displacements and the pore pressure as unknowns. In this work the latter is used.

After establishing the poroelastic plate theory by incorporating the classical kinematic assumptions of the Mindlin plate theory a variational principle for the poroelastic plate is developed leading, finally, to a Finite Element formulation. Based on this formulation, the flexural vibration of a Mindlin plate for varied material data is presented.

NUMERICAL STUDY OF DYNAMIC BEHAVIOR OF PILES AND PILE GROUPS IN POROUS SOILS USING THE BEM

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The study of the dynamic response of piles and pile groups has received attention from different researchers. In most cases the soil is assumed to be an elastic or viscoelastic solid. Little attention has been paid to the dynamic analysis of piles in water saturated soils. Very few studies exist where the two-phase character of the soil is taken into account in accordance to Biot¥s theory (see, for instance the works of N. Rajapakse). The existing solutions are rather limited on the soil properties or the pile geometry, and some times are based on non realistic simplified models.

In the present paper a Boundary Element approach for the frequency domain analysis of piles and pile groups embedded in fluid-filled poroelastic media is presented. The piles are assumed to be linear viscoelastic solids with their actual geometry and the soil as a homogeneous or zoned half space which may contain poroelastic and viscoelastic regions. Nine- and six-node quadratic elements are used for pile and soil surface discretization. Dynamic stiffness components for one pile and several pile groups are presented. Results are compared with others when they exist in the literature. The influences of the frequency of excitation and poroelastic effects on the response are examined. The interaction effects between piles of the same group for different geometries are also analyzed. The present Boundary Element approach is general and easy to use.

Dynamics of Multiphase Porous Media Using a Finite Element Framework

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Simulating the behavior of porous media is important for many fields of engineering and science such as civil engineering, petroleum engineering, mechanical engineering, biomedical engineering, material science, and geophysics. A porous medium typically consists of a solid skeleton and a number of fluids occupying the pore space. When subjected to loads, the behavior of porous media is highly nonlinear and time dependent, and therefore is ideally suited for simulations using computational techniques. This paper will present simulations of the dynamic behavior of a porous medium containing two fluids obtained using a finite element framework. A framework represents a collection of common software components for building different computer codes. The basic premise behind the use of a framework is the recognition of a common set of tasks that must be accomplished in writing any computer application code. These tasks can be factored out of the application codes and collected into a single set of components. The goal is to separate the physics aspects from the computer science aspects of writing a computer code and thereby making the code development more efficient. The example presented is the three-dimensional behavior of an unsaturated soil embankment subjected to earthquake loads. The fully coupled differential equations governing the behavior of the soil skeleton, pore water, and pore air are solved using a finite element framework. The nonlinear stress-strain behavior of the soil skeleton is modeled using elastoplastic constitutive models. Following a brief description of the theory, the framework will be described and the simulation results will be presented.

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NUMERICAL STUDY OF DYNAMIC BEHAVIOR OF PILES AND PILE GROUPS IN POROUS SOILS USING BEM

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ABSTRACT

In the present paper a Boundary Element approach for the frequency domain analysis of piles and pile groups embedded in fluid-filled poroelastic media is presented. The piles are assumed to be linear viscoelastic solids with their actual geometry and the soil as a homogeneous or zoned half space which may contain poroelastic and viscoelastic regions. Nine- and six-node quadratic elements are used for pile and soil surface discretization. Piles are bonded to the surrounding medium along the contact surface where rigorous pile-soil interaction conditions are imposed. Dynamic stiffness components for one pile and several pile groups are presented. The influences of the frequency of excitation and poroelastic effects on the response are examined. The interaction effects between piles of the same group for different geometries are also analyzed. The present Boundary Element approach is general and easy to use.

Keywords: Poroelastic Soil; Piles; Pile-Soil Interaction; Dynamics; Boundary Elements.

INTRODUCTION

The study of the dynamic response of piles and pile groups has received considerable attention from different researchers. In most cases the soil has been assumed to be an elastic or viscoelastic solid. Little attention has been paid to the dynamic analysis of piles in water saturated soils. Very few studies (Zen & Rajapakse, 1999; Jin et al., 2001; Wang et al., 2003) exist where the two-phase character of the soil is taken into account in accordance to Biot´s theory (Biot, 1956). The existing solutions are rather limited on the pile-soil contact condition or the pile geometry.

Boundary Element Methods (BEM) based on boundary integral equations are very well suited for dynamic soil-structure interaction problems. They have become a very extended approach for the solution of this type of problems due to their ability to represent unbounded regions in a

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natural way. The radiation of waves towards infinity is automatically included in the model, which is based on the integral representation of internal and external regions. In the present paper, a 3-D coupled frequency domain Boundary Element (BE) approach suitable for the analysis of dynamic impedances of piles and pile groups embedded in a poroelastic half-space is presented. Piles are modelled as continuum elastic or viscoelastic solids and surrounding soil as a fluid-filled poroelastic region. BEM are used for both pile and soil. The BE formulation used for poroelastic media was obtained by Domínguez (1991) and Cheng et al. (1991) after developing and integral equation formulation from Biot's differential equations. The geometry of piles can be general, including the actual cross section, inclined piles or groups of different piles. The soil may consist of poroelastic and viscoelastic zones with a more complicated underground geometry. Dynamic pile-soil interaction is taken into account by equilibrium and compatibility conditions along contact surface. Contact condition can be pervious or impervious. Selected numerical results for vertical and horizontal impedances are presented. The influence of the excitation frequency, poroelastic material properties, and foundation geometry, on the response are examined. A more comprehensive study, including formulation and several numerical results, can be found in a paper by the authors (Maeso et al. 2004).

BOUNDARY ELEMENT MODEL

The dynamic stiffness matrix of a foundation relates the vector of forces (and moments) $\boldsymbol{R}$, applied to the foundation and the resulting vector of displacements (and rotations) $\boldsymbol{u}$.

$$\boldsymbol{R} = \boldsymbol{K}\ \boldsymbol{u} \tag{1}$$

Dynamic stiffness terms for a time harmonic excitation are functions of frequency ω and are usually written as:

$$K_{ij} = k_{ij} + i a_0 c_{ij} \tag{2}$$

where k_{ij} and c_{ij} are the frequency dependent dynamic stiffness and damping coefficients, respectively, a_0 is the dimensionless frequency

$$a_o = \frac{\omega\, d}{c_S} \tag{3}$$

and c_S the soil shear-wave velocity. The coordinate's definition for a pile group can be seen in Figure1. Figure 2 shows the discretizations in BE used to calculate the stiffness of a pile and a group of 2×2 piles, respectively, embedded in a poroelastic half-space. Rectangular nine nodes and triangular six nodes elements are used. Since there is no closed form expression for the half-space fundamental solution, the fundamental solution corresponding to the complete space is used. Thus, not only the soil-pile interface, but also the soil free-surface, should be discretized. However, in practice only a small region around the foundation has to be included in the model.

Discretization criteria (size and shape of elements and length of free surface) have been studied in a previous work (Vinciprova et al., 2003).

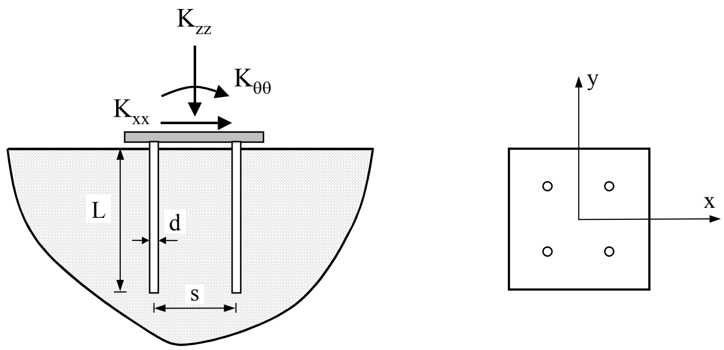

FIG. 1. 2×2 pile group embedded in a half-space. Problem geometry definition.

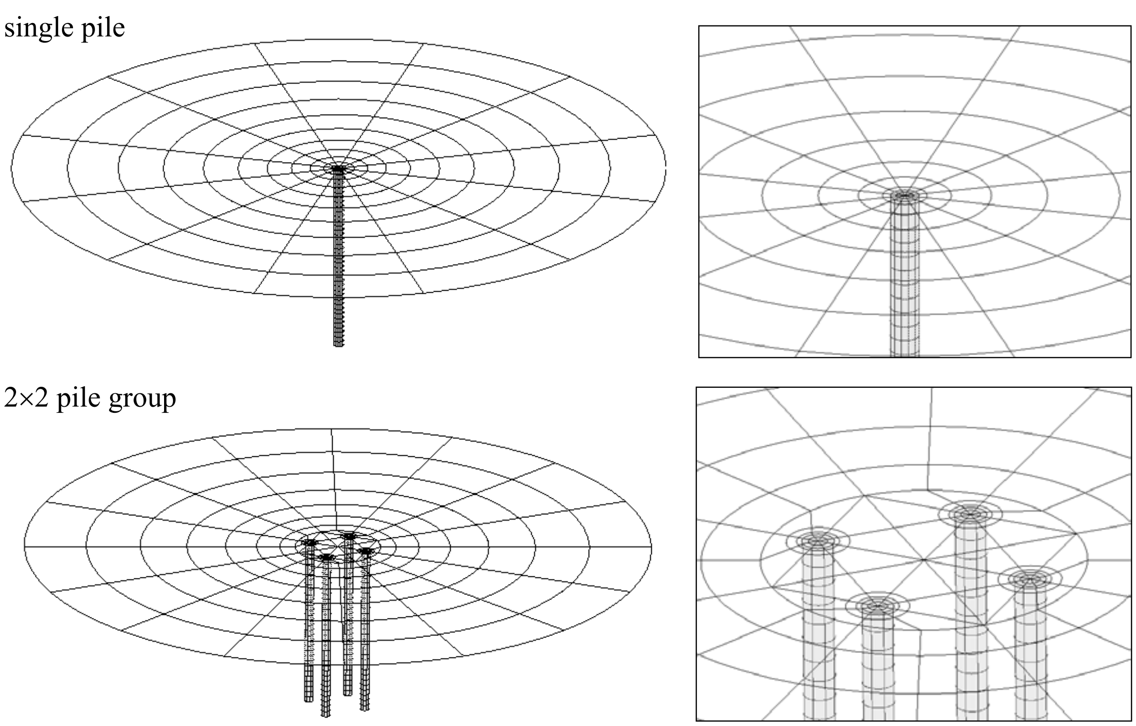

FIG. 2. Boundary Element discretizations.

Time harmonic displacement is prescribed at the pile cap. In Fig. 2 the top surface of the four piles are assumed to be connected to a rigid body and foundation stiffness is the addition of the contribution of each pile.

NUMERICAL RESULTS AND DISCUSSIONS

Following Zeng and Rajapakse (1999) the first results showed with the procedure described before correspond to the vertical impedance of a single pile embedded in a uniform poroelastic half-space. The properties of two-phase poroelastic soil are detailed in terms of the non-dimensional parameters whose definition is shown in Appendix: $\lambda^*= 1.5$, $Q^*= 2.87$, $R^*= 2.83$, $\rho_s^* = 1.44$, $\rho_f^* = 0.53$, $\rho_a^* = 0$ and two different values of the permeability that correspond to the values of the non-dimensional dissipation constant $b^*= 232.15$ and $b^*= 0$. The porosity is $\phi = 0.482$. The pile (denoted by sub-index p) is an impervious elastic medium whose properties are defined by: flexibility ratio $E_p/E = 10^3$ (with E = drained Young´s modulus of poroelastic medium), mass density ratio $\rho_p/\rho = 1.2$ (with ρ = bulk material density) and Poisson's ratio ν_p= 0.3. The pile aspect ratio is $L/d = 10$. Figures 3a and 3b show, respectively, the results obtained from the real and imaginary parts of the vertical stiffness, normalized with respect to the static stiffness value K_{zzo} for a drained elastic soil. The impedance is represented here in a way different from that used by Zeng and Rajapakse. The non-dimensional frequency a_o is defined by the Eq. (3), where c_s = bulk material shear wave velocity. A very good agreement with Zeng and Rajapakse solution is observed. It is also noticed that stiffness (real part) and damping values (imaginary part) are higher for larger b^* (less pervious medium). This effect of the permeability of the soil on the dynamic impedance will be studied afterwards with greater depth.

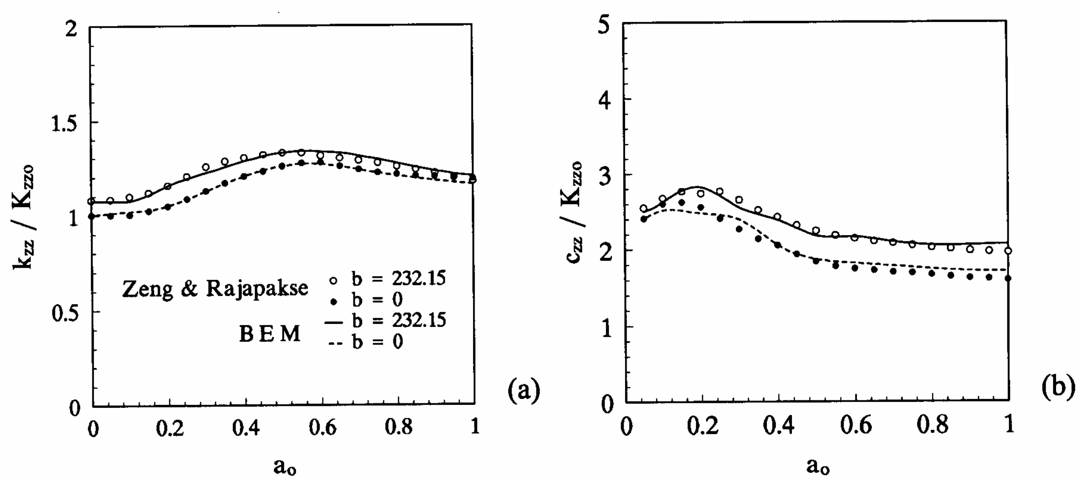

FIG. 3. Impedance of single pile in a poroelastic half space. Comparison with Zeng's solution.

In what follows, results for dynamic impedances of 2 × 2 pile groups embedded in a saturated poroelastic half-space, whose properties have been taken from Kassir and Xu (1988), are presented. Normalized values of properties of this medium properties are: $\lambda^*= 1$, $Q^*= 14.33$, $R^*= 7.72$, $\rho_s^* = 1.12$, $\rho_f^* = 0.78$, $\rho_a^* = 0$ y $b^*= 59.30$. Porosity is $\phi = 0.35$ and internal damping coefficient of the skeleton $\beta = 0.05$. Viscoelastic behaviour is assumed for the piles with properties of concrete: flexibility ratio $E_p/E = 343$ (E = drained Young´s modulus of poroelastic medium), mass density ratio $\rho_p/\rho = 1.94$ (ρ = density of bulk material), Poisson's ratio $\nu_p = 0.2$ and zero internal damping coefficient. The piles aspect ratio is $L/d = 15$. Impervious contact condition between piles and soil are considered. The influence of the poroelastic effects relative to the medium permeability (dissipation constant b) on the dynamic impedances is evaluated in this example. Dissipation constant b (inversely proportional to permeability k) affects in a significative way the dynamic response: high values of b (clays) imply a greater difficulty in the fluid transit through the solid skeleton as compared to low values of b (loose sands).

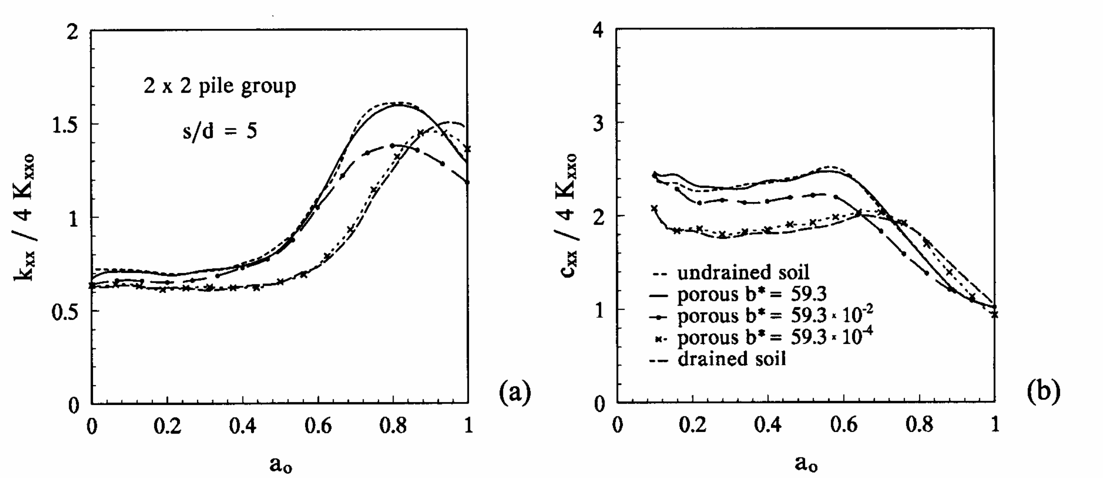

FIG.4. Influence of soil permeability. Horizontal impedance. 2×2 pile group;*s*/*d* = 5

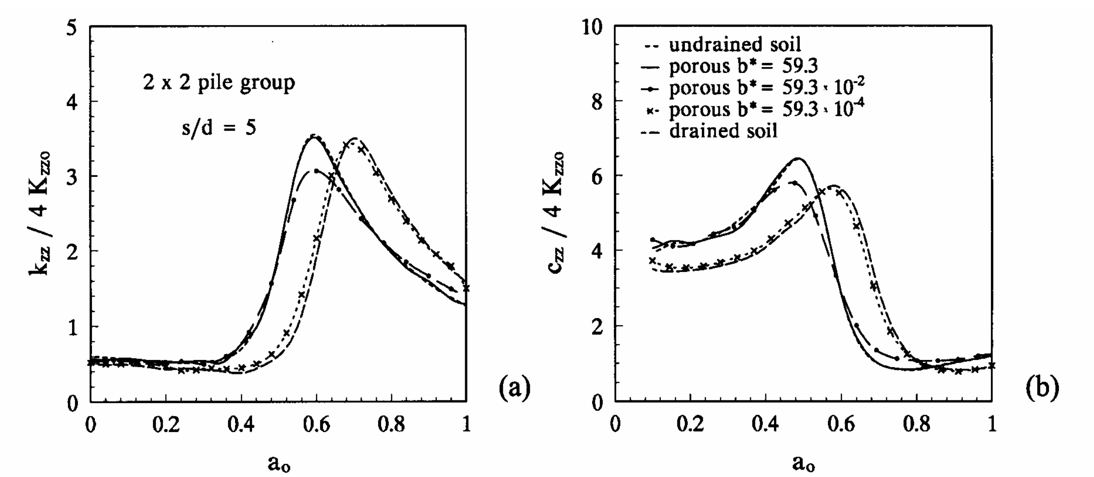

FIG.5. Influence of soil permeability. Vertical impedance. 2×2 pile group;*s*/*d* = 5

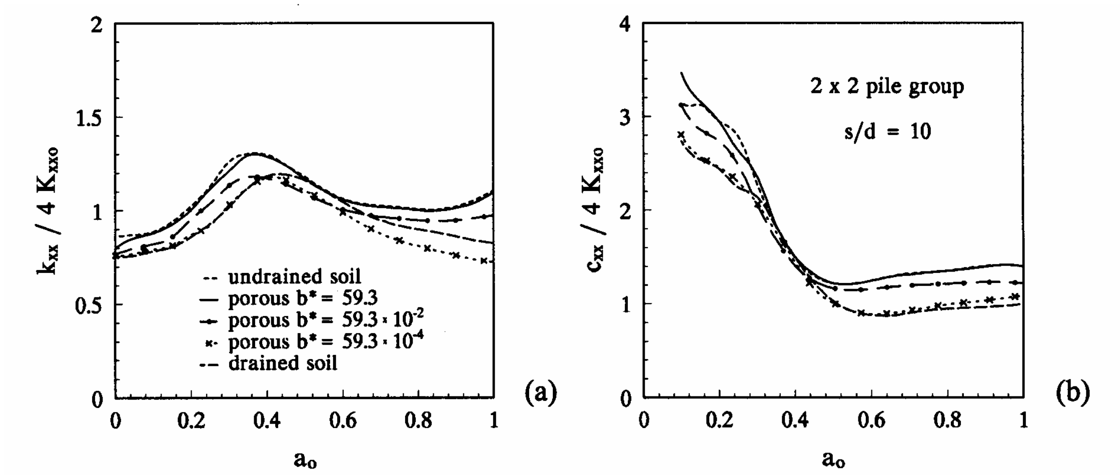

FIG.6. Influence of soil permeability. Horizontal impedance. 2×2 pile group;*s/d* =10

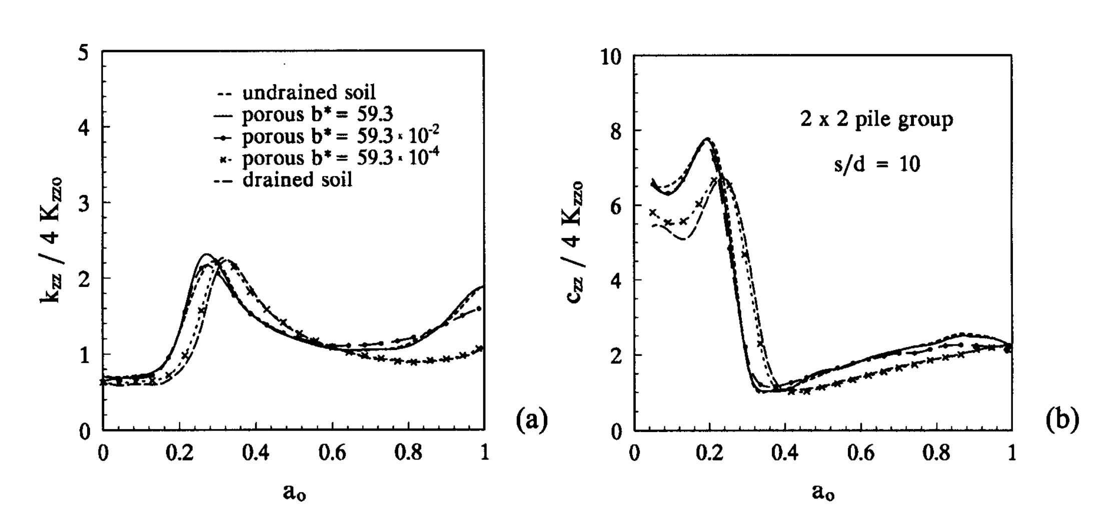

FIG.7. Influence of soil permeability. Vertical impedance. 2×2 pile group;*s/d* = 10

Three values for b^* have been assumed: $b^* = 59.3$, 59.3×10^{-2} and 59.3×10^{-4}. Figures 4 and 5 show, respectively, the horizontal and vertical impedances of a group of 2 × 2 piles with separation $s/d = 5$. For s/d = 10 the results are presented in the Figures 6 and 7. The Figures also show impedances corresponding to the two ideal limit single-phase media: drained elastic soil and un-drained elastic soil. High values of b^* bring the behavior of the two-phase medium near the un-drained ideal elastic soil, except, as can be expected, at low frequencies. It is observed that the dynamic response of a pile group, as compared to the single pile, is something more complex.

In the pile group case wave reflection phenomena taking place between piles depend on their separation and the medium properties. This causes increases and decreases of the stiffness in certain frequency ranges. Because of that, higher impedance values may be found in media with smaller values of b^*. Thus, one can see in figures 4a, 5a and 7a, higher stiffness maxima for $b^* = 59.3\times10^{-4}$ than for $b^* = 59.3\times10^{-2}$. This effect is combined with curves displacement towards the right side for increasing permeability. It is made possible by the increasing of the propagation velocities in the porous medium with permeability, and by the fact that in all cases the velocity used to normalize the frequency a_o in (3) is the one of the S-wave in a un-drained medium (which is its lower limit). Finally, the real part of the horizontal stiffness for a very pervious poroelastic medium can be lower than for an elastic drained soil, as it is noticed in Fig.6a. This fact is also observed for the single pile case(not shown),

CONCLUSIONS

In the present paper, a three-dimensional BE approach for the computation of time-harmonic dynamic stiffness coefficients of piles and pile groups embedded in two-phase poroelastic soils has been presented. Piles are modelled as continuum elastic or viscoelastic solids and the surrounding medium as a fluid-filled poroelastic half-space. The technique has been applied to the calculation of vertical and horizontal dynamic impedance functions of cylindrical single piles and 2×2 pile groups. Piles are assumed to be fully bonded and pile-soil interaction effects are taken into account through equilibrium and compatibility conditions at interfaces. Impedance results have been presented and it has been studied the influence of aspects such as: frequency of excitation, effects of pile-soil-pile interaction and permeability of the saturated soil.

The influence on the dynamic behaviour of the dissipation constant b (dependent on the fluid viscosity and the intrinsic permeability of the skeleton) is big because it affects noticeably soil wave velocities. In general, increasing values of dynamic impedances with b are obtained, tending towards the values corresponding to an ideal elastic un-drained soil.

Very pervious porous soils yield lower horizontal stiffness values than those corresponding to the ideal elastic drained soil. This effect is not observed in the vertical stiffness case.

Dynamic impedance values of pile groups are more frequency dependent than those of single piles due to dynamic pile-soil-pile interaction effects. This effect depends on the distance between piles and the soil properties.

In conclusion, simulating the dynamic behaviour through a drained or un-drained single-phase model can lead, depending on the medium properties and the geometric configuration of the foundation, to unrealistic results. Models for the dynamic analysis of piles and pile groups in poroelastic soils should include all the significant material parameters as done by the technique proposed in this paper, which permits a more general and versatile representation than other existent techniques.

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APPENDIX

The material properties of the poroelastic soil are normalized as follows (Zeng and Rajapakse,1999):

$$\lambda^* = \frac{\lambda}{\mu} \qquad \rho_s^* = \frac{\rho_s}{\rho} \qquad \rho_f^* = \frac{\rho_f}{\rho} \qquad \rho_a^* = \frac{\rho_a}{\rho} \qquad \text{(Aa-d)}$$

$$Q^* = \frac{Q}{\mu} \qquad R^* = \frac{R}{\mu} \qquad b^* = \frac{b\,d}{\sqrt{\mu\rho}} \qquad \text{(Ae-g)}$$

where $\rho = (1-\phi)\rho_s + \phi\,\rho_f$ is the density of bulk material (ρ_s and ρ_f the solid and fluid phase densities respectively, ρ_a the added density and ϕ the porosity), λ and μ are the Lame constants of drained solid skeleton, Q and R the Biot´s constants, b the dissipation constant and d the pile diameter.