Dynamic stiffness of soft soils from PDA tests

Module dynamique de sols moux à partir d'essais PDA

J.A. Rodriguez
Civil Engineering Department, Pontificia Universidad Javeriana, Bogotá, Colombia

E. Velandia
Jeoprobe Ltda , Bogotá, Colombia

ABSTRACT

The results from large strain dynamic bearing capacity of piles built in very soft soils in the city of Bogotá are used to obtain dynamic shear modulus of the soils at large strains in the field. This data is very useful for a better understanding of the dynamic soil behavior of these soils for seismic response analysis. The method is illustrated with results from one site where down hole and dynamic cyclic triaxial data was available to compare with the results from the PDA tests. The method seems to provide a field measurement of dynamic shear modulus of these very soft soils that have proven otherwise very difficult to test in the laboratory due to the difficult in obtaining representative undisturbed samples.

RÉSUMÉ

Les résultads de tests de capacité portante à grandes déformations sur des piles construites dans les sols moux de la ville de Bogota sont utilisés pour trouver le module de cisaillement à grandes deformations des sols in situ. Cette information est trés utile pour comprendre le comportement dynamique de ces sols lors des analyses de réponse sismique. La méthode est illustrée avec les résultads d'une location où des essais de Down Hole et de triaxialle dynamique êtaient disponibles. Ceux-ci ont été comparés aux résultads obtenus en utilisant l'essai PDA. La méthode semble conduire à une mesure in situ du module de cisaillement de ces sols trés moux. Ces mesurements sont autrement trés difficiles de conduire au laboratoire parcequ'il est difficile d'obtenir des échantillons qui soient représentativement inaltérés.

Keywords : Dynamic stiffness, field tests, Large strain dynamic pile tests.

1 INTRODUCTION

The soils of the high plain where Bogotá is located are made of very soft lacustrine silts and clays in deposits that reach over 300 m deep encompassing deposits formed through all the Pleistocene and Olocene (Rodriguez, 2006). These very soft and compressible soils are difficult to sample and sensitive. Its stiffness is highly affected by decompression and also strains due to sampling and handling. Because of this, it is very difficult to obtain reliable data of stiffness degradation in the laboratory for seismic response studies (Rodriguez et al, 2007). Based on geophysical methods such as down hole (DH), or dispersion of surface waves, it is possible to obtain reliable soil stiffness data in the field at very low strains. For seismic response analysis it is also required to know the variation of stiffness with mobilized strain. To date there is no standardized tests to obtain this type of information in the field.

On the other hand, the large strain dynamic load tests of piles analysis (PDA) (ASTM D4945-08) is a short duration dynamic test that produce a deformations field in the soil that mobilize shear strains in proportion to the pile movement. The degree of shear strains mobilized could therefore be controlled to some degree by the impact energy in the test. The PDA tests are usually interpreted considering the dynamic system defined by the pile considering the interaction with the surrounding soil by means of elastic-plastic springs and dashpots (Goble et al, 1975) so that the measured force and velocity histories are matched with the model results. This way the friction along the pile and its base load are obtained. Other than this, very little analysis is given to the properties of the soil that produce this interaction with the pile.

The method considered in this paper takes the results of stress distribution along the pile under a given load obtained from the PDA analysis and uses a soil structure interaction model to obtain the distribution of soil properties (stiffness) along the pile that would match the measured pile response. This way a set of compatible soil stiffness under dynamic conditions at variable strains are obtained under the assumptions made for the soil-pile interaction model. If this model is reasonably precise, the computed soil properties should be representative of the actual dynamic soil stiffness at the levels of deformation considered.

2 BASIC CONSIDERATIONS

The interaction of the soil and the pile in general can be complex and uncertain. There may be slip along the pile-soil interface, after a non linear mobilization of the soil stiffness until shear failure along the interface occurs, if the friction along the pile is fully mobilized. Moreover, the strain levels are not uniform along the pile, since the displacement that produces the interaction varies with depth. These factors will influence the applicability of the proposed method unless they are appropriately considered.

In this paper the soils considered are very soft and plastic with the profile shown in Figure 1, and the piles considered are bored cast in place. These piles produce minimum disturbance to the surrounding soil during construction compared with driven piles, and develop a good bonding by the pressure of the concrete during pouring and subsequent hardening. During the test it is assumed that the soil remains attached to the pile and that it interacts with the pile with an equivalent elastic stiffness under the conditions of the test. These assumptions are considered reasonable since the displacement induced in the pile by the test is not large, and the soils are soft and plastic allowing them to deform in the close vicinity of the pile without suffering significant slippage during the test. These assumptions are

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consistent with the local practice that has shown that the adhesion of bored piles in these soils is equal to the soils undrained shear strength (Rodriguez, 2006).

Given these considerations the model used for the soil-pile interaction is linear elastic with full bonding at the pile soil interface. A static finite element linear elastic axisymetric code was used to calculate this interaction for a given load applied at the pile top obtained from the PDA interpretation. The model is defined with a number of soil layers along the pile whose stiffness is changed until de computed stress along the pile match within a given tolerance with eth computed stresses from the model. The problem formulated in this way becomes an inversion problem. In order to obtain an estimate of the soil stiffness of the soils a Levenberg Marquardt non linear least squares optimization algorithm (Gill and Murray, 1978) was used coupled with the finite element computation with a FORTRAN program set up for this purpose (Cano, 2009). The model was further refined using a commercial finite element program.

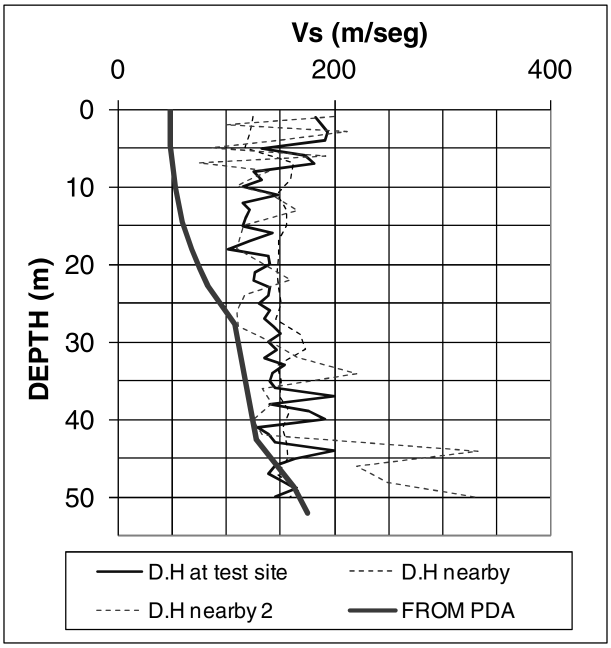

Figure 1. Shear wave velocity profile at the site and in the vicinity. The Vs profile obtained from the PDA analysis is also shown.

3 APPLICATION OF THE METHOD

For the application of the method data from a PDA test was available. The test was on a bored cast in place pile 52 m long and 0.6m in diameter was considered. Results from one blow where most of the pile capacity was mobilized by means of a 1.25m free fall drop of a 14 ton mass were considered. The data was analyzed by GRL USA (GRL Job No. 068053-1, 2006) and produced an equivalent static load of 620 ton at the pile top and corresponding stress distribution along the pile as shown in Figure 2. Figure 3 shows the computed vertical displacements of the pile.

The non linear system properties identification procedure outlined in the previous section was applied to obtain a profile of soil stiffness that would match the vertical stresses obtained in the PDA as shown in Figure 2. The displacements and strains along the pile obtained from the soil structure interaction model are shown in Figures 3 and 4. From these figures it seems that the stress were matched very closely, but there are some differences in the computed displacements between the two models in the first 20 m of the pile. This difference may be due to the fact that the FEM model is a continuous axisymetric model while the method used for PDA analysis is a finite differences one dimensional model with discrete springs and dashpots. Also the springs are elastic-plastic producing quakes or permanent displacements in the model as shown in Figure 3.

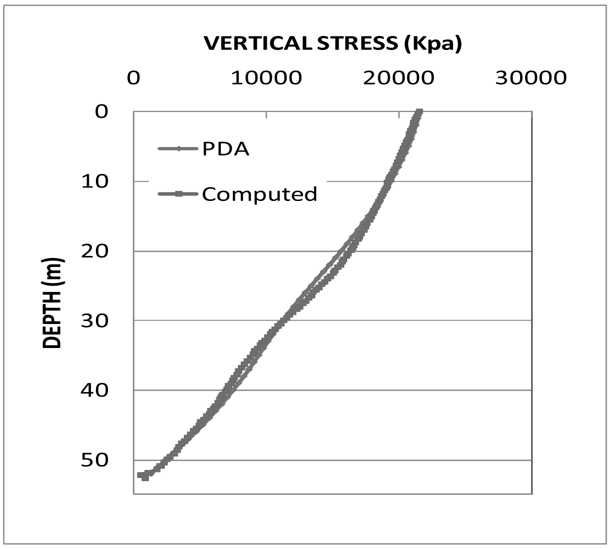

Figure 2. Vertical stress along the pile measured at the PDA test and computed from the pile soil interaction model.

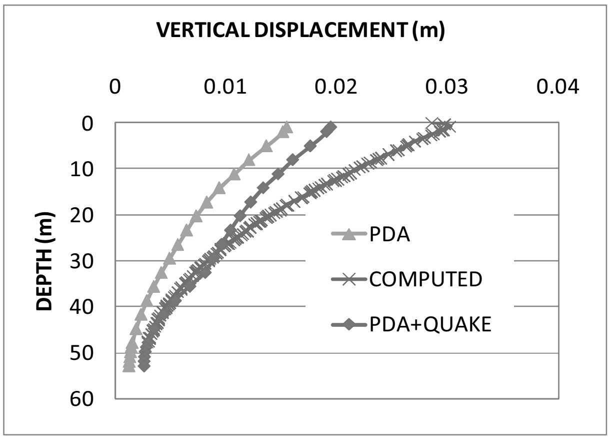

Figure 3. Vertical displacements along the pile obtained from the PDA analysis and the soil structure interaction model.

From the profile of soil stiffness obtained in the analysis the corresponding shear wave velocity (Vs) profile was computed using elastic formulas as shown in Figure 1 along with the low strain Vs profile obtained from down hole measurements. The data is consistent in that at shallow depths the strains mobilized in the soil are high and therefore the stiffness reduction is larger. At larger depths the mobilized strain is small and the Vs values obtained at the PDA test tend to the values of the undisturbed soil.

At this site a local seismic response study was previously conducted (Jeoprobe Ltda, 2006) for which soil samples and cyclic triaxial laboratory tests were done. From these tests soil degradation curves were obtained taking into account data reported in the literature (Ishibashi y Zhang, 1993), and also the results of a study conducted in order to revise the seismic microzonation of the city (RSMZB),(CGS, 2007). These curves are presented in Figure 5, and are considered to be representative of the soft clays found at the site that have plasticity index between 125 and 175. In Figure 5 the data points obtained along the pile from the soil structure interaction analysis are also shown. It can be appreciated that this data corresponds well within the curves obtained from the lab tests.

The data of dynamic shear modulus reduction with deformation is used to obtain the profile of modulus reduction values shown in Figure 6. Once again the data from Ishibashi y Zhang and the revised seismic microzonation of Bogotá is plotted together with the data interpreted from the field measurement. These results are also consistent and in good agreement, indicating that the field data lies very close the curves recommended from the CGS study, and below the data obtained from the Ishibashi y Zhang data. There is also the tendency of smaller modulus degradation at higher depths where the shear strains in the soils where smaller.

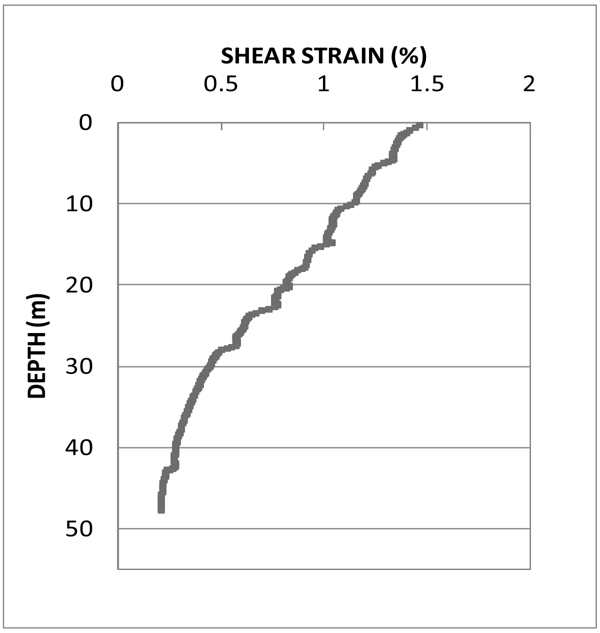

Figure 4. Computed profile of shear strains in the soil along the border of the pile.

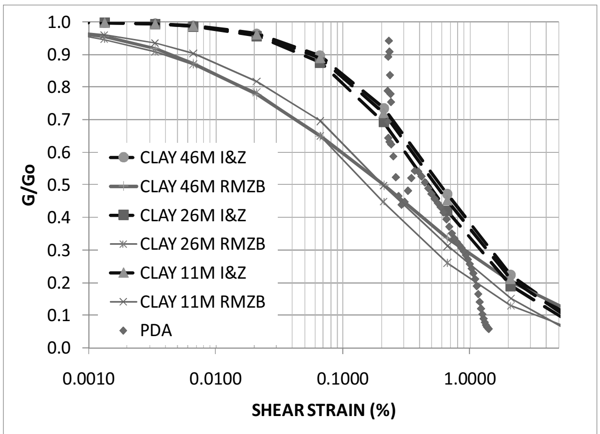

Figure 5. Dynamic stiffness degradation curves estimated for the site from the equations by Ishibashi and Zhang (I&Z), from the study for revision of the seismic microzonation of Bogota (RZMSB) and data points obtained from the PDA analysis.

4 CONCLUSIONS

A method for estimating soil dynamic modulus from measurements of large strain pile load tests in soft soils has been formulated and explored. The results seem to be reasonable and in good agreement with data obtained from field geophysical measurements and laboratory tests. This method holds a potential as an independent means for validating modulus degradation relationships for the soft soils in the city of Bogotá and potentially elsewhere, where obtaining reliable laboratory data is difficult.

In order to apply this method good data from PDA tests should be available, preferably for different levels of deformations induced at the pile test. Also the PDA analysis should provide a complete interpretation of the compressive stress along the pile.

The results of this method can also be used to cross validate different sets of data in the soil characterization, including geophysical measurements, laboratory data and the interpretation of the PDA test.

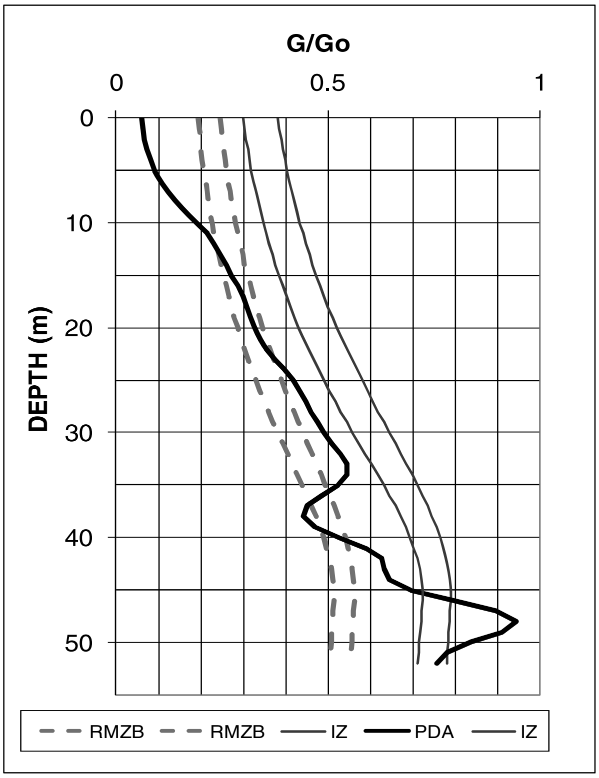

Figure 6. Modulus reduction values of the soil in close vicinity along the pile. Estimated from the data in Figure 5 and from the PDA analysis.

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