Load rate effects on high strain tests in high plasticity soils

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ABSTRACT: The behaviour (compressibility, creep, strength, and yield limits) of fine grained soils has been recognized to depend on strain rate. The dynamic load of piles (PDA) is conducted at very high load rates, in the order of 0.1 sec, while static load tests are done over a time frame in the order of 100,000 sec. The actual life span of the foundations is in the order of 10,000 times longer. This represents a 10^6 difference in load rate between the static and dynamic load test, and 5×10^7 with the actual life of the foundation. In case of high plasticity soils the viscous effect is very significant and therefore this aspect of the soil behaviour should be taken into account in the interpretation procedures of high strain tests. The strength increases significantly with strain rate, and therefore if this aspect is not properly considered, the predictions from dynamic load tests may be in the unsafe side. Two case histories are illustrated where static and dynamic load tests of friction piles were performed in a soft soils profile with plasticity indices in the range 150 to 300%. The results clearly show these effects, and it is shown that this can be taken into account based on available soil mechanics data for this type soils.

1 INTRODUCTION

The large strain testing of piles (PDA) is a dynamic problem under a very high strain rate compared to the service strain rate of the piles. This dynamic problem mobilizes significant inertial forces, as well as forces related with the rheology of the materials involved, particularly the soil pile interaction and the viscous nature of the soil itself. Chaure, 2004, has done a detailed review of how the load rates effects are considered on the behavior of piles under large strain dynamic loading. It shows how this effect is usually taken into account by a power law of the moving body with the exponent of the power law usually taken around 0.2 with additional rheological parameters depending on the formulation. This parameter J (Smith, 1960, Coyle & Gibson, 1970, Goble et al. 1975 – Case Method), has been tried to correlate with soil type or other quantities, but it is empirical and convenient for the mathematical description of the strain rate effects, but it does not have a clear relationship with soil behavior, and it has to be calibrated based on test data for different soil conditions.

On the other hand, it has been a known fact that the behavior of fine soils is strain rate dependent or equivalently it is said that these soils show viscous behavior. Berre & Bjerrum (1973), identified in the laboratory the dependence of the strength on the strain rate. Ishihara (1996, chapter 9) have identified how the shear strength of fine soils under earthquake load is higher than the strength in lab tests under different strain rates. Krieg (2000) show how the compressibility is also dependent on strain rate and how the secondary compression is also a manifestation of this behavior. He uses the viscosity index defined as the ratio between the coefficient of secondary compression to the primary compression index as the parameter that can be used to describe this behavior. This viscosity index correspond to the observations of the behavior of natural clays as described by (Mesri & Castro, 1983). Krieg presents data from different fine soils that indicate that the viscosity index is uniquely related to the liquid limit indicating a relationship with the mineralogy of the soils. The range of values for this parameter is between 0.02 for low plasticity soils, to 0.06 for very high plasticity soils. It can be shown that the viscosity index is the exponent that controls the relationship between the shear strength of fine soils at different load rates. Because of this that relationship, the difference in strength mobilized by the soil in an static pile load test compared to a dynamic load test will be in the range of 1.3 to 2.3 depending on the plasticity of the soil due to different strain rates applied in these tests.

2 STRAIN RATE EFFECTS ON SOFT SOILS

Murayama and Shibata (1958) and Mitchell et al. (1968) showed that the undrained shear strength is related to the strain rate in the form:

$$cu = cr(1 + Iv\ln(\gamma/\gamma r)) \qquad (1)$$

where cr is the undrained shear strength obtained at a given strain rate of reference γr. The proportionality factor Iv, is the viscosity index that depends on the plasticity of the soil and the temperature but it is independent of the strain rate. Mesri (1973), Mesri y Ajlouni (1997) showed that Cα, and Cc, are not cosntant, but that the ratio Cα/Cc is approximately constant. It can be shown that the value of the viscosity index can be obtained as: Iv = Cα/Cc. This parameter is related to the liquid limit as shown in Fig. 1 (Krieg, 2000).

3 TEST RESULTS

The strain rate effects have been observed to largely influence the PDA test results in the soft lacustrine clays in the city of Bogotá, where these soft high plasticity soils reach depths up to 200 m, and where most large buildings are founded on friction piles. Two case histories where both PDA and static load tests of piles have been carried out are illustrated. The soil strength was obtained from the pile load tests and normal soil strength tests both in the field (CPT, piezocone, and shear vane) and in the laboratory. The strengths were predicted based on the available data previous to the pile tests and it was compared with the mobilized during the tests. The pile of the first case history was 36 m long, 60 cm in diameter, bored cast in place with concrete. Due to the soft soils, the mobilized friction in this type of piles has been found to be very close to the intact shear strength of the soils. The pile was loaded by a heavy weight (14.5 ton) dropped up to 2 m height in the PDA tests. Also data from a static load test made by means of hydraulic jacks and reaction beams in the static test according to ASTM D1143 were available.

The profile of Atterberg limits and natural water content of the soils at the site is shown in Fig. 2. Liquid limits in the range of 100 to 275 are found at the site to depths up to 45 m, indicating the potential for high

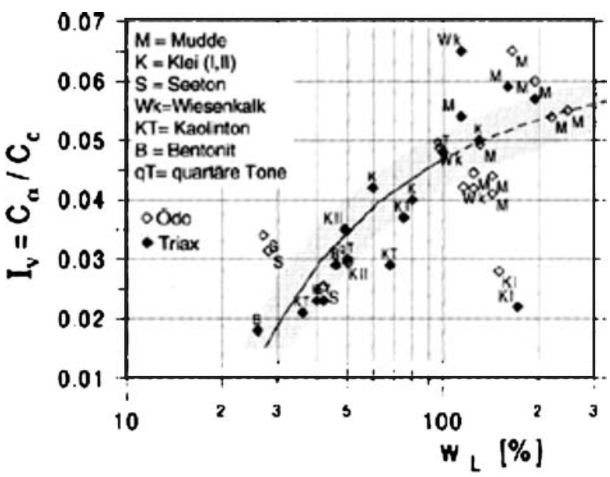

Figure 1. Viscosity Index as a function of liquid limit (Krieg, 2000).

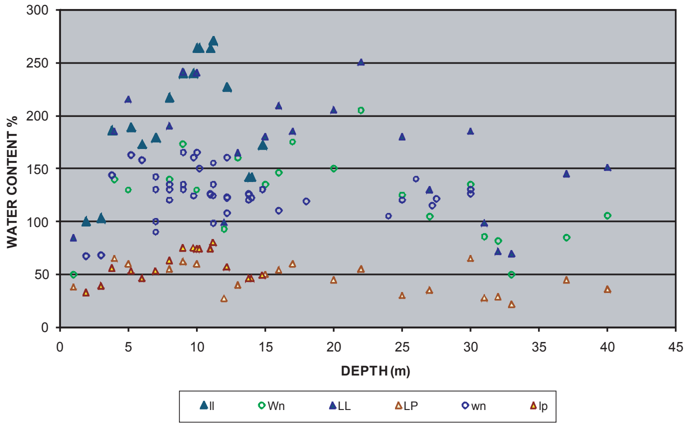

Figure 2. Plasticity and natural water content profile at the site.

values of viscosity index and large influence on soil strength due to dynamic effects.

The results from the PDA test are shown in Fig. 3, based on standard interpretation using CAPWAP analysis. The load capacity obtained from the test, without considering explicitly the effect of the strain rate on the soil strength produce a static load prediction 440 ton of which those 413 ton where predicted to be in side shear and 27 ton where predicted to be in end bearing resistance. Fig. 4 presents the static load tests results obtained for this same pile. The total static load test reached a plunging load of 390 ton.

The second case history entails the testing of 50 cm cast-in-place pile, with a total length of 26 meters. In this case, two sister piles were constructed, one was tested dynamically and the other was tested statically. The CAPWAP analyses for the dynamic test is presented in Fig. 5, and the total plunging failure

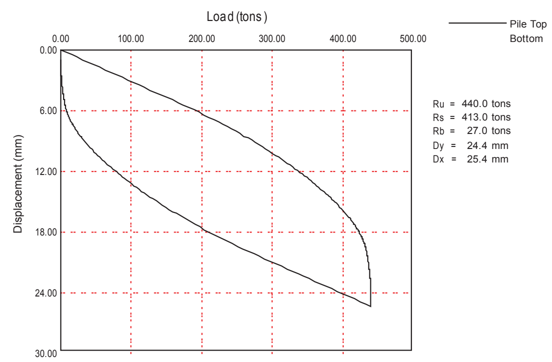

Figure 3. PDA Test Results Case History 1.

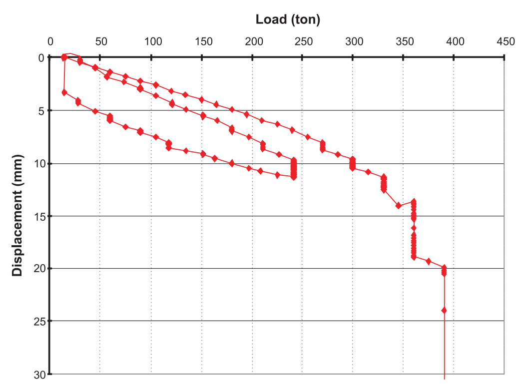

Figure 4. Static Load Test Case History 1.

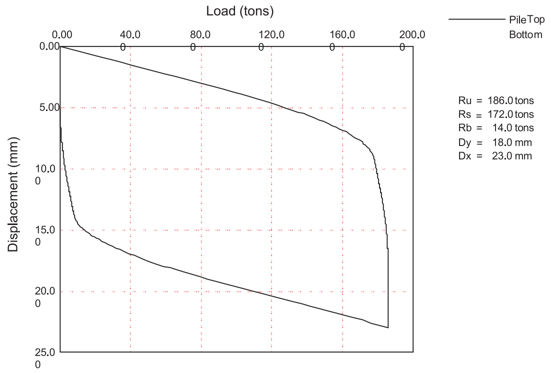

Figure 5. PDA Test Results Case History 2.

load was predicted to be 186 ton, with 172 ton in side shear. The static load test is presented in Fig. 6. The failure load obtained in the static test reached a plunging failure load of 144 ton.

For the initial case history an over prediction of the load of 11 percent was observed during the dynamic load tests and for the second case history this over prediction was of 23 percent.

It is considered that this difference is due to the viscosity effects that can be taken into account considering the increase in strength as given by eq. 1 and using the Iv values obtained from Figs. 1 and 2. In order to test this hypothesis the values of shear strength were obtained for the soil profile from the pile tests, both static and dynamic (measured soil resistance to driving in the dynamic tests), and from the soil exploration data that included CPT, piezocone and vane shear data. The "static" shear strength, was then corrected to the dynamic conditions considering the Iv value at each depth from correlation with the liquid limit, and compared with the strength derived from the dynamic pile load test as given by the PDA analysis. These data is shown in Fig. 7.

The results show that the predicted strength derived considering the viscous effect is at the strain rate of the PDA test is in well agreement with the strength obtained from the PDA test interpretation without considering the strain rate increase in soil strengths. The strength at high strain rate for these high plasticity soils is between 1.5 to 2.0 times the strength obtained in the normal soil exploration tests and from the static pile load test. The strain rate in the dynamic test is in the order of 106 times higher than in the static test. This over prediction during the dynamic tests in these high plastic soils must be taken into account.

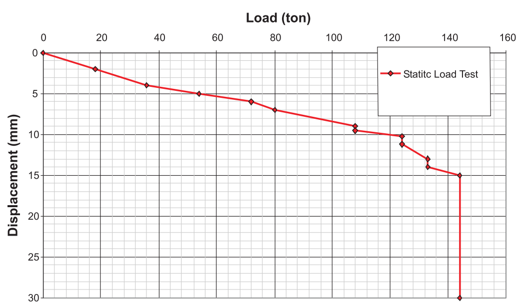

Figure 6. Static Load Test Results Case History 2.

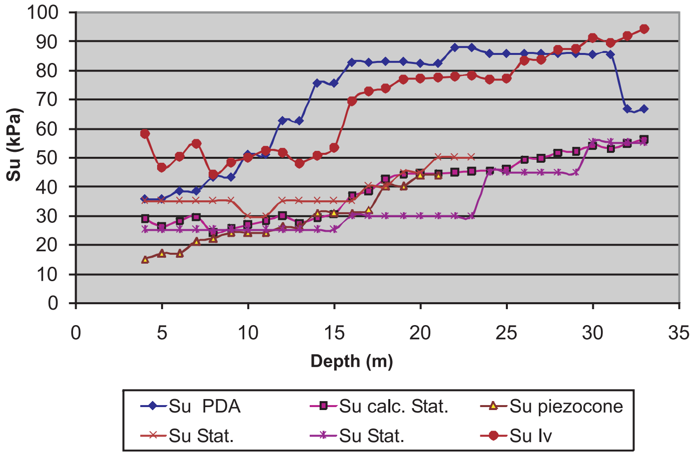

Figure 7. Shear strength Su (kPa), obtained from static and dynamic tests, and computed considering the soil's viscosity index.

Correcting the total resistance (static plus dynamic resistance) utilizing Iv and eq. 1 at each depth, a static load prediction can be obtained. For the initial case history the total predicted load is calculated to be 343 ton, while in the second case history the predicted load was 147 ton. Based on these computations the difference between the static load test and the calculated static capacity based on the mentioned procedure is 12% of under prediction for the pile in the first case history and the 2% of over prediction of the pile in the second case history.

Utilizing CAPWAP a new load set curve can be predicted based on the mentioned calculated load. The static load set curves and the simulated load set curves based on the mentioned procedure are presented in Figs. 8 and 9.

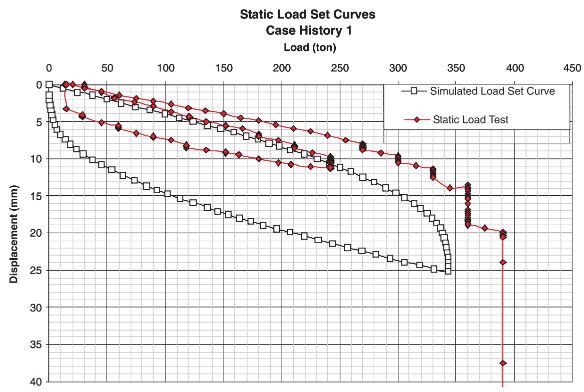

Figure 8. Static Load Test vs. Simulated Load Test.

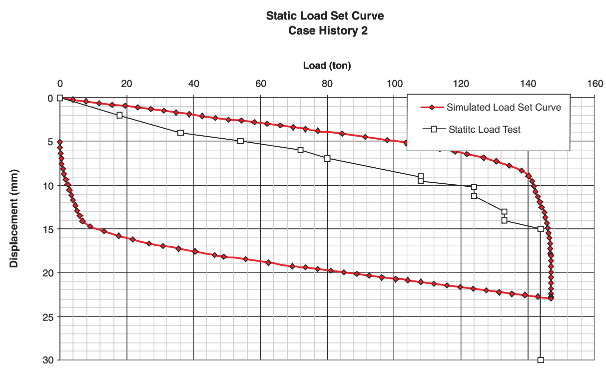

Figure 9. Static Load Test vs. Simulated Load Test.

4 CONCLUSIONS

The strain rate has an important effect on the soils strength for high plasticity soils and high strain rates. This is the case of the lacustrine soils in the city of Bogotá when PDA tests are used to predict or control the capacity of piles. Evidence for this behavior is the differences observed in sites where piles have been tested under static (ASTM D1143) and dynamic conditions. Taking into account the effect of strain rate based on well established data on the viscous behavior of fine grained soils it is possible to correct the shear strength and bearing capacity obtained from dynamic tests. This is very important in soils with high plasticity since the difference was observed to be in the unsafe side.

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