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Classification of soils using in situ ultrasonic velocity techniques
Classification des sols sur base de techniques de mesure aux ultrasons

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ABSTRACT: In the present paper the indirect ultrasonic velocity technique was used for in situ investigation of soils. The tests were performed in Kozani - Grevena area, in Northern Greece, which was affected by the earthquake of 13-5-95 (Ms=6.6). The buildings in the area were damaged and the soil mechanic tests were used in order to give information for microzonation studies.

The main goal of this investigation was to determine a soil classification methodology using an ultrasonic velocity tester in order to estimate the mechanical behavior of soils for urban planing. This method has already been used for measuring the dynamic parameters and the surface weathering conditions of building stones, so the aim of the investigation is to provide it's accuracy in determining those parameters of soils. The test results will be used for estimating the suitability of these soils for urban planning.

RÉSUMÉ: Dans le cadre de la présente étude, l'appareil portable PUNDIT fut utilisé pour des tests in situ concernant la vitesse de propagation d'ultrasons dans le sol. Les tests furent réalisés dans la région de Kozani - Grevena, dans le Nord de la Grêce, région affectée par le tremblement de terre du 13 mai 1995 (Ms=6.6). Les bâtiments de cette zone furent endommagés et des tests de mécanique des sols ont été utilisés dans le but de récolter des informations pour des études microzonales.

L'objectif principal de cette étude est de déterminer une méthode de classification des sols utilisant un test aux ultrasons pour estimer le comportement mécanique des sols lors de planing urbain. Cette méthode a déjà été utilisée pour mesurer les propriétés dynamiques et l'altération de surface de pierres de construction. Le présent objectif est de prouver sa précision pour la détermination du module de Young dynamique et du coefficient de Poisson des sols.

Les résultats des tests sont examinés dans l'optique de déterminer l'aptitude de ces sols à servir pour le planning urbain.

1 INTRODUCTION

The portable PUNDIT machine gives a direct reading of the time of transmission of an ultrasonic pulse passing from a transmitting to a receiving transducer.

The quality of some materials is sometimes related to their stiffness so that measurement of ultrasonic pulse velocity in such materials can be used to indicate their quality as well as to determine their elastic properties.

When ultrasonic testing is applied to materials (soils, rocks, concrete, metals) its objective is to detect internal changes in their structure (flaws), composition or other properties (physical, mechanical) which send echoes back in the direction of the incident beam and these are picked up by the receiving transducer.

For assessing the quality of materials from ultrasonic pulse velocity measurement, it is necessary for this measurement to be of a high order of accuracy. This is performed using an apparatus which generates pulses and accurately measures the time of their transmission (i.e. transit time) though the material tested. The distance, which the pulses travel in the material (i.e. the path length) must also be measured to enable the velocity to be determined from:

$$\text{Pulse velocity} = \frac{\text{Path length}}{\text{Transit time}}$$

The instrument indicates the time taken for the earliest part of the pulse to reach the receiving transducer measured from the time it leaves the transmitting transducer when these transducers are placed at suitable points on the surface of the material.

Having in mind that soils are characterized by large damping of the transmitted wave signals, it is easy to understand why it is so difficult to detect them and measure their ultrasonic velocities. Additional to this is the reason why we can only take measurement in small distances and why the errors are more important in long distances. Particularly, in cohesive soils the PUNDIT tester can give signals in distances until 20-30 mm even 1m but in noncohesive soils we cannot take measurements in distances more than 10-15mm.

The pulse velocity is not affected by the frequency of the pulse so that the wavelength of the pulse vibrations is inversely proportional to this frequency. Thus the pulse velocity will generally depend only on the properties of the materials and the measurement of this velocity enables an assessment to be made of the condition of the material.

2 GEOLOGY

This investigation has been carried out in Kozani - Grevena area (Fig. 1), in Northern Greece, which was affected by the earthquake of 13-5-95 (Ms=6.6).

Geologically, the affected area is mainly consisted of Pliocene and Pleistocene formations composed of lacustrine and fluvial deposits, such as clay, loam, sand, conglomerate etc, as well as miocene molassic formations, mainly composed of sandstones and conglomerates. Triassic - Jurassic limestones are also observed.

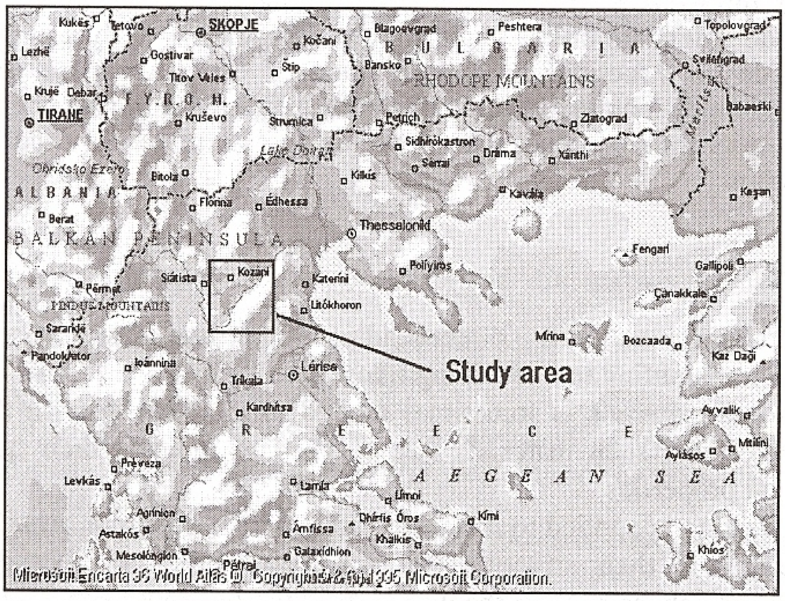

Figure 1. Location of the study area.

According to our tests the soil formations present a big range of grain size distribution, being classified in cohesive silty sand (sandstone), marl, pure sand, very cohesive sand, clayey sand, fine sand, medium sand, silty clay, and clay. Their properties differ significantly from site to site providing suitable or unsuitable soils for the construction.

Thus, loose sand with very low shear strength and clay or silty soils with very low permeability and high plasticity and compression index characterize unsuitable soil type in which statistically a great number of recent buildings were damaged. On the other hand, areas consisted of rocks or cohesive soils, presenting high permeability and low (or none) compressibility, provided a relatively less significant damage phenomena (Christaras et al, 1996).

3 METHODOLOGY

The main goal of this investigation was to determine a soil classification methodology using an ultrasonic velocity tester (Fig. 2) in order to estimate the mechanical behavior of soils for urban planing.

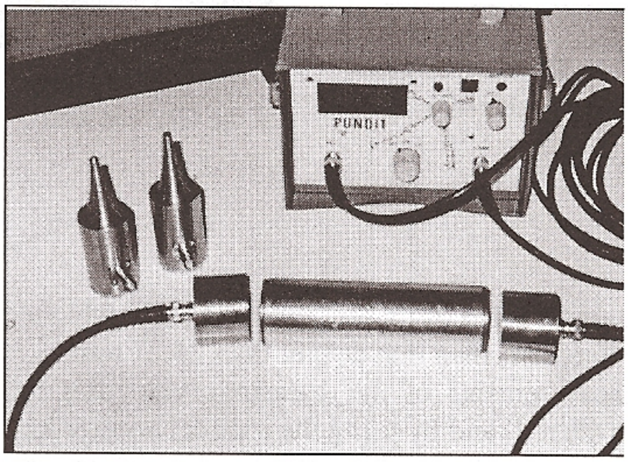

Figure 2. The portable ultrasonic tester.

The transducers of the ultrasonic velocity tester can be arranged on the surface of the specimen tested directly or indirectly.

The direct transmission arrangement is the most satisfactory one since the longitudinal pulses leaving the transducers are propagated mainly in the direction normal to the transducer face. In general, the pulse velocity determined by the indirect method of testing will be lower than that using the method. The indirect arrangement is the least satisfactory because, apart of its relative insensitivity, it gives pulse velocity measurements which are usually influenced by the layer near the surface and this layer may not be representative of the formation in deeper layers. According to this, the depth of weathering at a stone surface can be evaluated using the indirect velocity technique (Zezza, 1993; Christaras, 1997). In this case the transmitters are placed on a suitable point of the surface and the receiver is placed on the same surface at successive positions along a specific line. The transit time is plotted in relation to the distance between the centers of the transducers. A change of the slope in the plot could indicate that the pulse velocity near the surface is much lower than it is deeper down in the soil formation. This layer of inferior quality could arise as a result of weathering.

The thickness of the weathered surface layer may be estimated as follows:

$$D = \frac{Xo}{2}\sqrt{\frac{Vs - Vd}{Vs + Vd}}$$

Where:
Vs: pulse velocity in the sound soil (km/sec)
Vd: pulse velocity in the damaged soil (km/sec)
Xo: distance at which the change of the slope occurs (mm)
D: depth of weathering (mm)

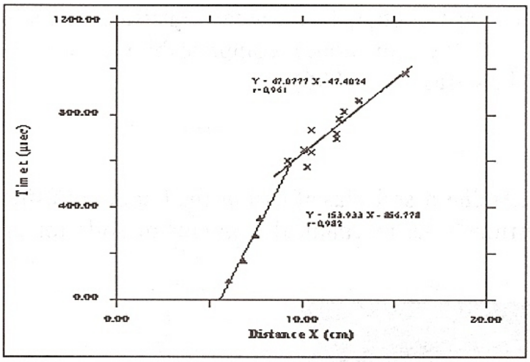

Figure 3. Determination of the weathered surface layer.

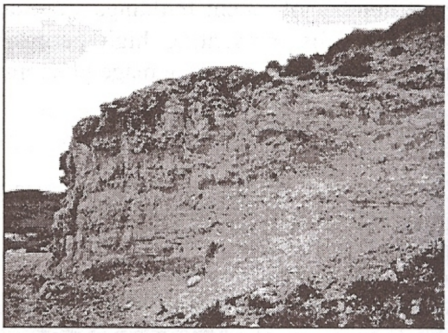

Figure 4. Study trench, near Sarakina village of the Grevena area.

In figure 3 there is an example of a representative diagram which corresponds to a soil formation which surface has different v_p than that deeper than 24.27 mm.

In this investigation, the measurements of the ultrasonic velocities has been carried out in trenches of about 1.5-2 m depth (Fig. 4) and by using the indirect arrangement of the transducers.

The measurements have been carried out along the bedding of the studied formation, after removing the weathered surface. There has been used both the conical (with and without the amplifier) and the cylindrical transducers (Fig. 5, 6, and 7).

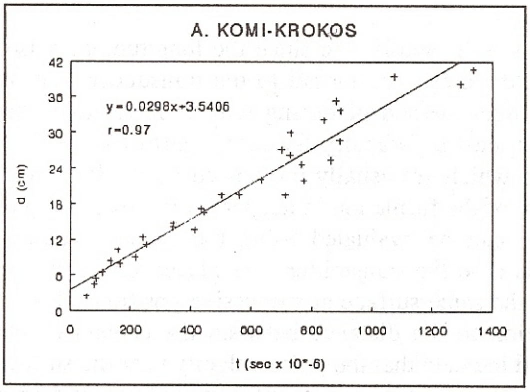

Figure 5. A t,d diagram, when the conical transducers were used.

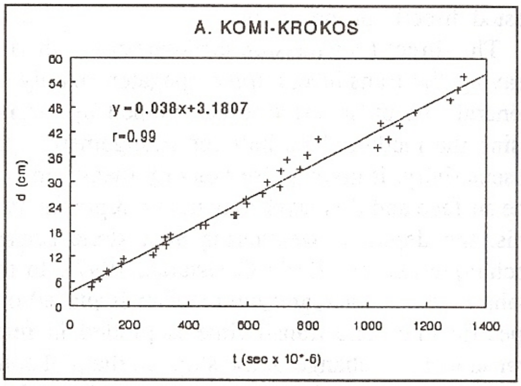

Figure 6. A t,d diagram, when the conical transducers with amplifier

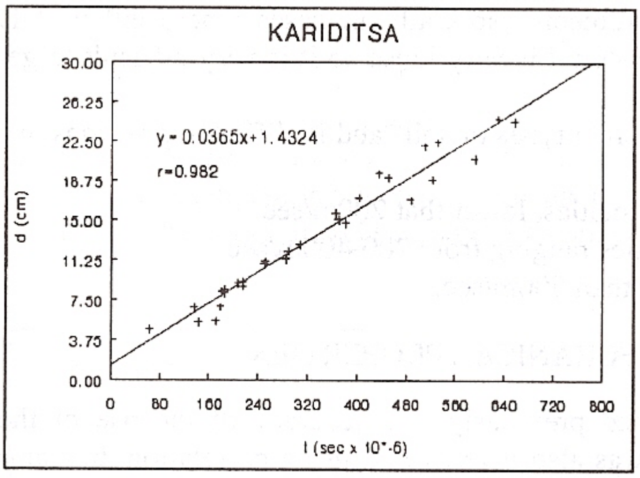

Figure 7. A t,d diagram, when used the cylindrical transducers with nails.

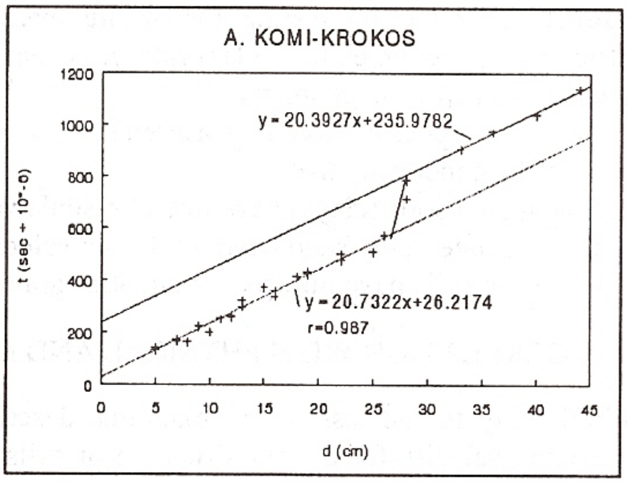

Figure 8. A t,d diagram, when used the cylindrical transducers

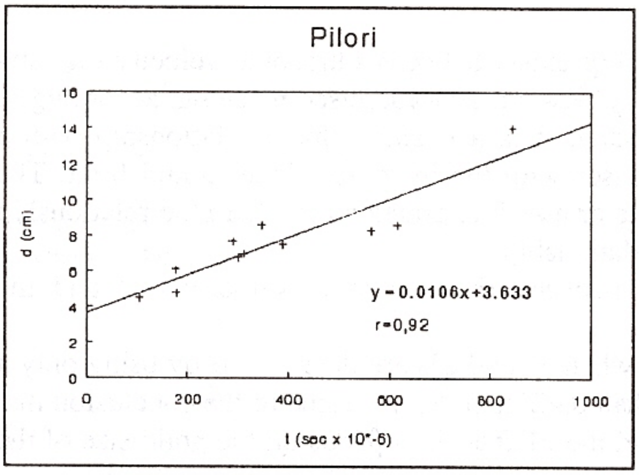

Figure 9. A correlation between the measurements when used conical and cylindrical transducers.

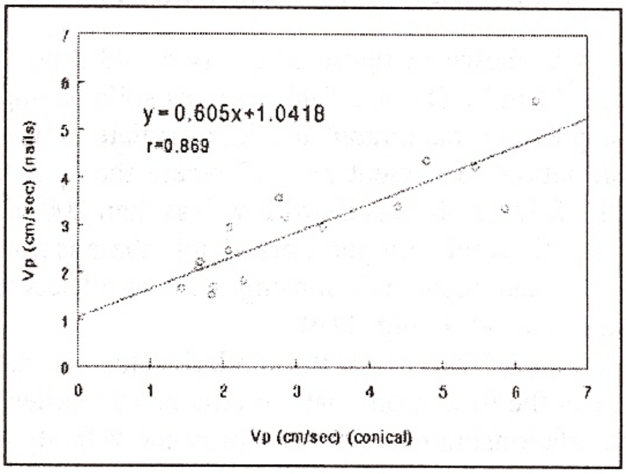

Figure 10. A correlation between the measurements when used conical and cylindrical transducers with nails.

The ultrasonic velocity of a material (in this case a soil) is influenced by the temperature (Timur, 1977), the moisture content and the structure. To avoid those influences, there have been used big nails (15mm long) with the cylindrical transducers in order to take measurements in deeper parts of the formation (Fig. 8 and 9).

The advantages of that method are:

1. The ability to reach the most sound as possible (for surface measurements) part of the formation.
2. The ability to take measurements in positions (narrow or rough surface of the formation) where it was not possible with the cylindrical transducers.

A regression diagram between the measurements using conical and cylindrical transducers with nails, showing a significant correlation, is presented in figure 10.

The fact that the diagrams between the transit time versus the path length of the ultrasonic velocities that has been measured, using the indirect method, in the study area, are linear with very high correlation coefficient (r>0.9), proves the reliability of this method.

Taking into account all the above mentioned, we considered that the measurement of the ultrasonic velocity could be used as a method that could be used for the classification of soils. The indirect method is interesting for in situ measurements especially in cases where either it is difficult to get samples to the laboratory, or the material is very loose so it is very difficult to get specimens in specific geometry.

For this purpose by taking measurement in different types of soils and in different positions, we reached the conclusion that:

1. Fine grated soils (clays) have low ultrasonic velocities, lower that 200m/sec.
2. Intermediate - silty sand have ultrasonic velocities ranging from 200-400m/sec.
3. Cohesive soils have ultrasonic velocities grater than 500m/sec.

4 CORRELATION WITH PHYSICAL AND MECHANICAL PROPERTIES

Additionally to the test of the diagrams described previously, the accuracy of the use of the ultrasonic velocity for the classification of soils was also investigated using correlation diagrams with physical and mechanical properties, like plasticity and elasticity. For this purpose different soil types were tested at representative sites.

Liquid Limit (LL) and Plasticity Index (PI)

As it is shown in figure 11a, a two-fold relationship exists between ultrasonic velocity (v_p) and Liquid Limit. The one fold involves soils having v_p between 200-400m/sec meaning, according to the previous paragraph, the intermediate - silty sand. It is a positive linear relationship with a correlation coefficient r= 0.92 where the v_p increases with the increase of the Liquid limit. The other fold involves soils with v_p less than 200m/sec or else fine grated soils where the relationship is negative and very poor, practically there is no relationship.

An analogous relationship can be observed between the ultrasonic velocity (v_p) and the Plasticity Index (Fig. 11b).

The explanation for these relationships is that when PI and LL are determined by using only a part of the formation, that with diameter smaller than 0,425mm. So we come to the conclusion that the relationship between the ultrasonic velocity and the PI and LL depends on the grain size of the soils.

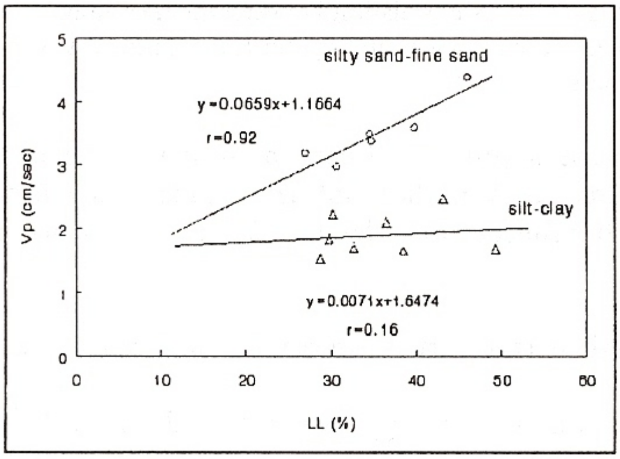

Figure 11a. Correlation between the v_p and the LL.

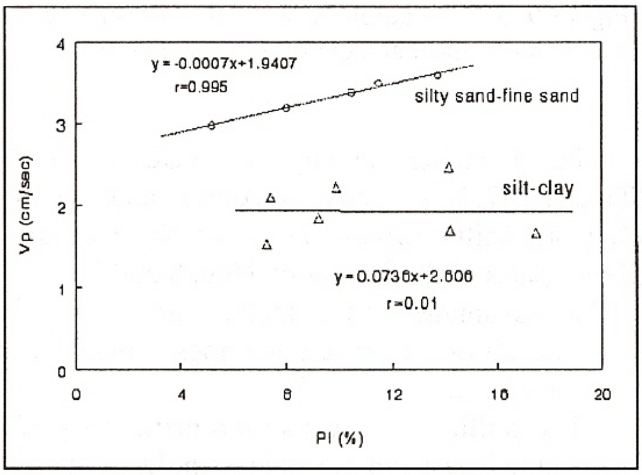

Figure 11b. Correlation between the v_p and the PI.

Elastic Modulus (static and dynamic)

In this investigation the dynamic Elastic Modulus of the soil formations has been defined in connection with the v_p and the density, ρ, by:

$$E = \rho V_p^2 \quad \text{(Gazetas, 1996)}$$

As it is shown in figure 12a, a power relationship exists between the ultrasonic velocity (v_p) and the dynamic Elastic Modulus where the v_p increases with the increase of the E. It is characteristic the fact that the equation which connects the two factors is similar to that mentioned above.

Figure 12b shows the relationship between the v_p and the static Elastic Modulus (E_{st}) which is a polynomial one.

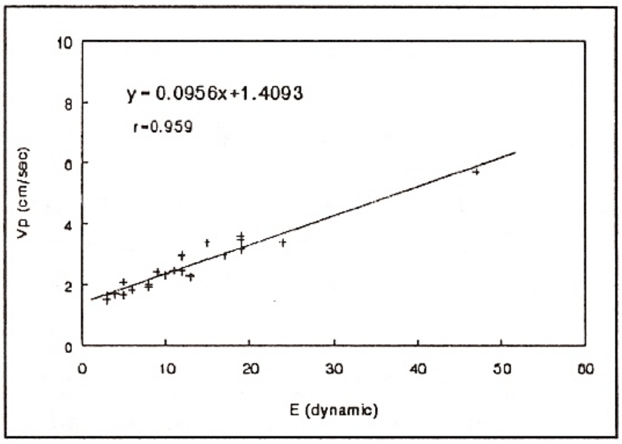

Figure 12a. Correlation between the v_p and the dynamic Elastic Modulus.

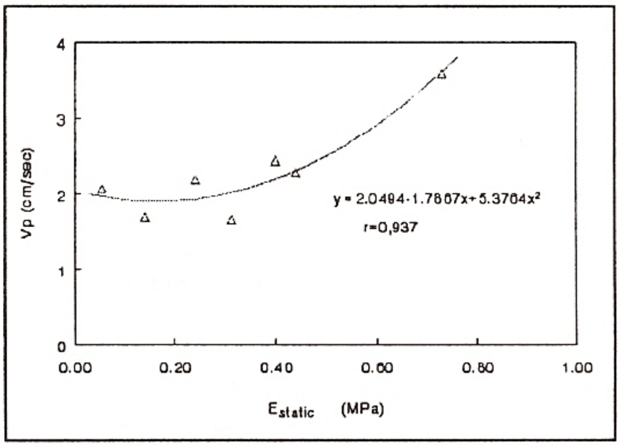

Figure 12b. Correlation between the v_p and the static Elastic Modulus.

5 CONCLUSIONS

1. The ultrasonic velocity can be used as an in situ classification method for soils.
2. Low ultrasonic velocity values correspond to fine grated soils (clays). So low v_p means high plasticity, settlement etc.
3. Ultrasonic velocity between 200-400m/sec corresponds to intermediate - silty sands and the cohesive soils have ultrasonic velocity grater than 500m/sec.
4. The v_p increases with the increase of the Elastic Modulus.
5. The correlation with the liquid limit and the plasticity index depends on the grain size of the soil and that accounts for the positive and the negative relationship of the silty sands and the clays and silts respectively.

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