SPECIAL INVESTIGATIONS REQUIRED RELATED TO OLD STRUCTURES
ENQUETES SPECIALES RELATIVES AUX ANCIENNES STRUCTURES

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SYNOPSIS: This paper covers the use of special non-conventional methods to obtain geotechnical information in historical constructions where the preservation of the zones investigated is of paramount importance. Among the different in situ techniques available to the geotechnical engineer, geophysical methods such as resistivity profiling, propagation of surface waves and ground penetrating radar, have been selected due to their non-destructive character. Using those methods the Geotechnical Laboratory of the Public Works Study and Research Center (CEDEX) has collected valuable data concerning the behaviour of some facilities existing at the historical site of Alhambra in Granada.

INTRODUCTION

In the following sections a brief review is made of some experimental and analytical procedures that can be used to investigate the geotechnical behaviour of old structures. To illustrate their application, two constructions in Alhambra site have been choosen.

RETAINING WALL IN THE SULTANA YARD

In the palace that used to be the summer house of the medieval sultans there is a very old 5 m high retaining wall which in the spring of the year 1991 exhibited large lateral displacement that could endanger its stability. Due to the historical value of the structure, and in order not to interfere with visitors to the palace, it was decided to stabilize the wall by strengthening its backfill material. Accordingly, it was grouted using sleeve pipes, the pressure and flow of the grouting mixture being controlled very strictly. The methods used to assess the physical conditions of the backfill material before and after that treatment are briefly commented in the following paragraphs:

DC Resistivity profiling

Resistivity prospecting methods employ an artificial source of current which is introduced into the ground through point electrodes and potentials are measured at other electrodes in the vicinity of the current flow. Assuming a given distribution of actual resistivities in the ground and solving the differential equation that governs the distribution of the electric potential around a point source of current, the potential values at different points can be determined and compared with the potential values measured in situ. If they differ by a substantital amount the actual resistivity model can be modified to obtain a new solution and the process be repeated until a reasonable agreement between the theoretical and measured values is reached.

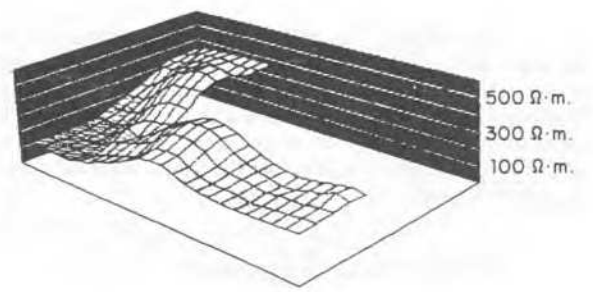

Fig. 1. Apparent resistivity values determined with double-dipole arrays on the backfill of Sultana yard.

To investigate the degree of compactness of the backfill material before it was grouted, several resistivity profiles were carried out on its surface employing a double-dipole array. Then a Finite Element program was used to set up a theoretical model for the distribution of actual resistivities within the backfill mass. At each step of the trial and error process used to reach a final solution, the apparent resistivity values calculated were compared with those measured in situ. Figure 1, shows a 3-D plot of the latter values. The high resistive zones identified in the model, indicative of high porosity non-saturated materials, were later on confirmed by the high admission rates detected when grouting those particular zones.

Spectral Analysis of Surface Waves.

Surface wave methods, not requiring the drilling of boreholes for the determination of shear wave velocities within a soil mass, are now becoming widely accepted among engineers. Basic to the method is the determination of the so called dispersion curve in the field which reflects the geometrical and elastic properties of the different ground layers at each observation point. Among the different procedures existing to collect data in situ, the Spectral Analysis of Surface Wave method (SASW), Stokoe and Nazarian

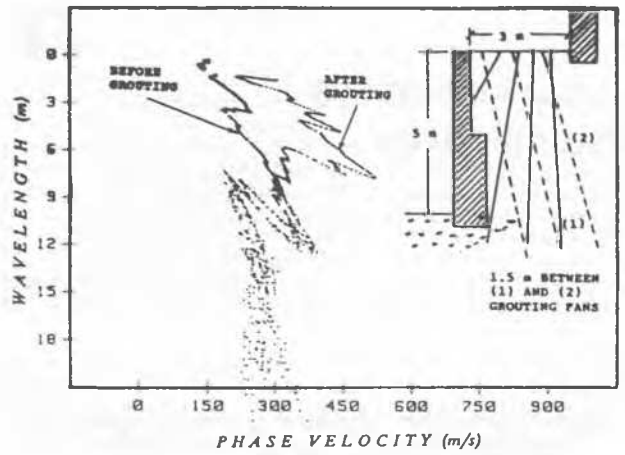

Fig. 2.- Dispersion curves obtained from backfill at Sultana yard.

(1984) has proved to be a highly cost-effective non-destructing technique Cuéllar (1992). The test is conducted by placing two recievers on the ground surface at a preselected spacing and appliying a vertical impulse at a certain distance to generate a transient signal containing the range of frequencies needed to construct the dispersion curve at the middle point between receivers.

With a view to checking the efficiency of the grouting in the Sultana yard, surface wave tests were carried out on the backfill before and after the treatment, and dispersion curves similar to those indicated in Figure 2 were obtained at different points. The interpretation of those curves led to post-grouting shear moduli of the backfill ranging from 5 to 10 times the values obtained before the injection took place.

WALL FOUNDATION IN SANTA ELENA CASTLE

In order to investigate the foundation conditions of the walls in Santa Elena castle, located in a place locally known as "the moorish chair" on top of the Alhambra site, the following tchniques have been used:

Seismic refraction

Several surveys, parallel to the walls, were performed in the interior yard of the castle. They were implemented with others in the outside perimeter of the structure. The interpretation of the seismic profiles allowed the determination of a surficial layer in the ground, with a low P-wave velocity value, reaching a maximum thickness of 5 m near a zone of the wall where signs of large settlements had been observed.

Ground penetrating radar

To further explore the existence of anomalies in the subsoil, that could affect the behaviour of the walls, several ground penetrating radar profiles were obtained with a 500 MHz antenna. This technique, being based in the analysis of the arrival times and amplitudes of the reflections experienced by short pulses of electromagnetic energy, can be used to obtain information about the

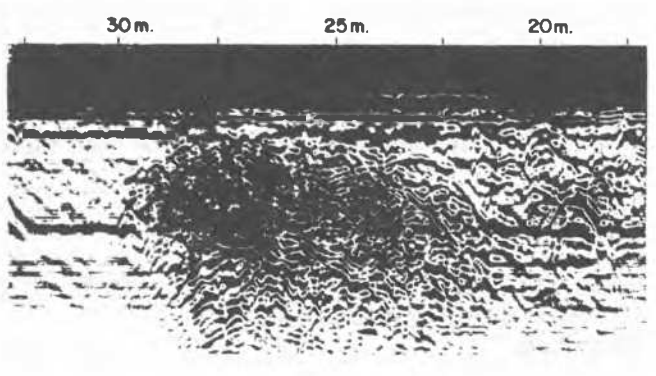

Fig. 3.- Distinctive materials identified in a radar profile close to the wall of Santa Elena castle.

location and nature of dielectric discontinuities inside a material mass, Cuéllar et al. (1993). Its high degree of resolution makes it a very suitable method to delineate buried features close to the ground surface that can affect the behaviour of civil constructions. Figure 3 shows the continuous profile of wiggle traces constructed with the reflected energy captured by the antenna in one of the traversees carried out besides a zone where the wall was badly cracked. The disturbed zone in that figure revealed the existence of distinctive materials and small cavities in the ground through which water from heavy rains could easily percolate down to the foundation system of the wall affecting its shear resistance.

CONCLUSIONS

Geophysical methods, such as those commented in this work, when applied correctly constitute reliable procedures to obtain the elastic properties of soil foundations, to detect anomalous zones in the ground and to judge the degre of improvement achieved with some ground treatments. Their non-destructive character makes them very adecuate to investigate the foundation conditions of old buildings and monuments of great historical value.

ACKNOWLEDGEMENTS

Special thanks are given to Dr. Mateo Revilla, Director of Patronato de la Alhambra for his support to achieve this study

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