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Applications of PS suspension logging test in port infrastructures

Applications de l'essai de diagraphie de la suspension PS dans les infrastructures portuaires

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ABSTRACT: This work has its origin in a research project focused on the characterisation by geophysical methods of different materials present in port infrastructures and the seafloor on which they are founded. The study centered on obtaining the mechanical properties of the materials, so mainly seismic methods were applied. One of the most important conclusions of the study was the verification of the excellent results provided by the PS suspension logging test, which is the reason why this technique has subsequently been used in different technical assistance and research works applied in several Spanish ports. It is a very versatile technique as it only requires one borehole which can be cased or uncased and, in addition, the values of V_P and V_S can be obtained very accurately at any depth. This paper presents the results obtained with the PS suspension logging probe in different applications: temporal evolution of the stiffness of landfills and ground improvement treatments, localisation of the rocky substrate, checking the state of the concrete of old quays, characterisation of the natural seafloor for the construction of a new quay, etc. With these results, on the one hand, the main advantages of the PS logging probe are highlighted: versatility and accuracy; on the other hand, its most important limitations are also indicated: length of the probe and sensitivity to high seismic noise.

RÉSUMÉ: Ce travail trouve son origine dans un projet de recherche axé sur la caractérisation par des méthodes géophysiques de différents matériaux présents dans les infrastructures portuaires et le fond marin sur lequel elles sont fondées. L'étude s'est concentrée sur l'étude des propriétés mécaniques des matériaux, c'est pourquoi des méthodes sismiques ont été appliquées. L'une des conclusions les plus importantes de l'étude a été la vérification des excellents résultats fournis par le test de diagraphie de la suspension PS, raison pour laquelle cette technique a ensuite été utilisée dans différents travaux d'assistance technique et de recherche appliqués dans plusieurs ports espagnols. Il s'agit d'une technique très polyvalente car elle ne nécessite qu'un seul trou de forage qui peut être tubé ou non tubé et, en outre, les valeurs de V_P et V_S peuvent être obtenues avec une grande précision à n'importe quelle profondeur. Cet article présente les résultats obtenus avec la sonde PS dans différentes applications: évolution temporelle de la rigidité des décharges et des traitements d'amélioration du sol, localisation du substrat rocheux, vérification de l'état du béton des anciens quais, caractérisation du fond marin naturel pour la construction d'un nouveau quai, etc. Ces résultats mettent en évidence, d'une part, les principaux avantages de la sonde de diagraphie PS: polyvalence et précision ; d'autre part, leurs principales limites: longueur de la sonde et sensibilité aux bruits sismiques élevés.

Keywords: PS logging, port infrastructures, stiffness, S-wave.

1 INTRODUCTION

Between 2016 and 2019, a research project was conducted to characterize port fill materials and the underlying natural ground using various geophysical methods. The study aimed to find the most suitable combination of methods and compare results with other geotechnical tests for validation. In this study, it was of particular interest to understand the mechanical properties of the materials, so seismic methods were primarily applied.

The work was addressed in two phases: in the first, the effectiveness of different geophysical techniques applied was verified at a site where the geotechnical profile was known; The second phase consisted of the application of some of these methods to study the foundation of a maritime station to be built on a port reclamation land that has been in service for several years. One of the most important conclusions of the study was the verification of the excellent results provided by the PS suspension logging test (Tijera et al., 2019), which is the reason why this technique has subsequently been used in different technical assistance and research works applied in several Spanish ports. It is a very versatile technique as it only requires one borehole which can be cased or uncased and, in addition, the values of V_P and V_S can be obtained very accurately at any depth.

In this paper, different applications of this technique in port infrastructures have been selected to illustrate its versatility.

2 PS SUSPENSION LOGGING

The PS suspension logging is employed to accurately determine the mechanical properties of the ground surrounding a borehole at various depths.

This technique involves measuring the propagation velocities of elastic waves (V_P and V_S) within a 1-meter radius around the borehole walls. The waves are induced by an impulsive source inside the equipment, necessitating the borehole to be filled with water or mud to ensure the transfer of disturbance from the source to the borehole walls and subsequently to the ground. The resulting waves, traveling parallel to the borehole axis, are detected by sensors positioned 1 meter apart in depth within the probe and recorded in a central unit (Kitsunezaki, 1980). The primary goal is to achieve precise measurements of ground properties through this logging technique.

Its main advantage is its precision at any depth. Its main weaknesses are high sensitivity to ambient noise, spurious vibrations (Tijera et al., 2023); and its length, the probe is about 6 m long.

3 APPLICATIONS

3.1 Characterisation of hydraulic fills and natural ground

In this initial example, a summary of the results obtained using PS suspension logging is presented in the context of a geotechnical study aimed at determining the design of the foundation for a maritime station in the Port of Ibiza. This work constituted the second phase of the research project mentioned in the introduction. The geophysical investigation was carried out in the esplanade of a dock that, at that time, was used for material storage. The esplanade was composed of a fill of clayey sands, and the main objective of the geophysical campaign was to identify the presence of the rock bed.

The measurement campaign, conducted in 2018, was divided into two trial groups: those performed from the surface and those carried out inside two previously drilled mechanical boreholes. From the surface, the Surface Wave Seismics (SASW) and Multichannel Analysis of Surface Waves (MASW) techniques were applied (Foti et al., 2017), while inside the boreholes, measurements were conducted using the PS logging probe, as well as electromagnetic and natural gamma probes (Ellis et al, 2007).

The combination of seismic methods both on the surface and inside the boreholes enhances the results, leveraging the accuracy of internal measurements and the extrapolation capability to large areas, such as port areas.

The PS logging probe played a crucial role in calibrating continuous measurements taken from the surface, allowing for a precise determination of the depth of the rock beneath the port area. In Figure 1, the results of V_S obtained through various techniques, namely PS logging, MASW, and SASW, are presented. The survey extensions for SASW and MASW, as depicted, were centered on the borehole where PS logging was introduced. The rock at that point was accurately located at a depth of 19 m, as indicated by the red dotted line in the figure. Measurements with the PS logging were made every 0.5 m depth. The spacing of the sensors in the SASW test varied between 0.5 m and 20 m. In the MASW tests, an array of 24 geophones spaced 2 m was used and moved along the entire length of the esplanade. The results are presented from the first-metre depth to avoid the high-velocity layer of the surface pavement.

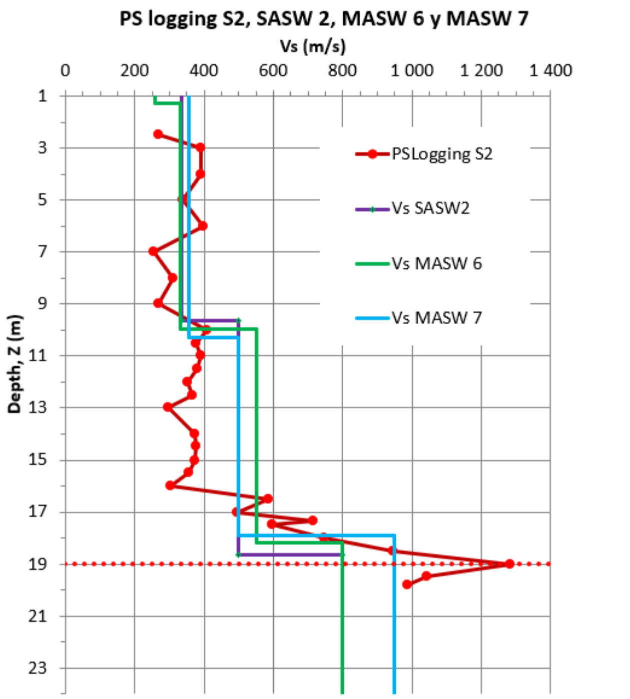

Figure 1. Vs values obtained with the different seismic tests in the vertical of one of the drilled boreholes. The rock is located 19 m at that point.

3.2 Assessment of the integrity and quality of port quays

The second example chosen to illustrate the good results of the PS probe is its application to study possible structural damage in a port quay. The work aimed at assessing the integrity and quality of a reinforced concrete diaphragm wall in the Port of Huelva, Spain, using a combination of field and laboratory tests. The diaphragm wall consists of 250 T-shaped elements which are strongly reinforced. Each element is 3 m wide and long and 0.6 m thick, and all of them are anchored to a rear passive wall. The depth of the diaphragm wall is 34 m, counting the capping beam (3 m). The contact with the seabed is 12 m from the surface. In 2018 a series of sinkholes appeared in the quay near the cantilever beam, prompting this research work.

The study employs seismic methods, including PS suspension logging tests and seismic tomography combining surface and borehole tests, to assess anomalies in wave propagation velocities (V_P and V_S) associated with material continuity loss. These tests help identify defects in the structure, particularly at joints. Additionally, laboratory tests, such as unconfined compression and ultrasonic pulse velocity tests on borehole specimens, are conducted to quantify concrete quality.

In 2019, a 3D ground-penetrating radar (GPR) campaign revealed anomalies near the capping beam, and a visual inspection exposed defects in joints. Subsequently, in May 2020, 5 vertical boreholes were drilled at different points of the quay to assess the condition of the concrete. The boreholes served multiple purposes: visual inspection, laboratory testing, seismic testing, and installation of inclinometer pipes for monitoring potential movements.

The field tests, including PS suspension logging and seismic tomography, consistently show high values of V_P and V_S below the capping beam, indicating good concrete quality. Laboratory tests on extracted cores further confirm the high quality of the concrete, with unconfined compression and ultrasonic pulse velocity values within ranges associated with excellent quality.

The study emphasizes the good correlation between field and laboratory results, reinforcing the conclusion that the concrete within the diaphragm wall is of good quality. PS logging played a key role in this study as it provided a link between the large-scale surface tests (tomography) and small-scale laboratory tests. The results obtained with PS logging helped to determine that the defects were in the joints, ruling out large losses of material inside each element. Figure 2 shows the values of V_P and V_S obtained in the different boreholes studied with PS suspension logging. The high velocity values indicate the good quality of the concrete in the section of the screen above the seabed (12 m), which is the area susceptible to material leakage. These results agree with those of the other tests:

- Seismic tomography: 4300 m/s< V_P <5000 m/s
- Laboratory tests: 4200m/s< V_P < 5000 m/s.

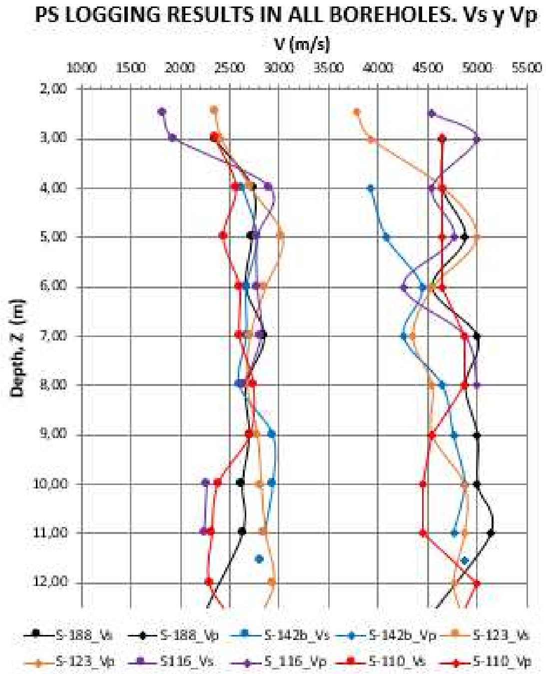

Figure 2. V_S and V_P values obtained in the different boreholes in the section of the screen above the seabed.

3.3 Time evolution of mechanical properties

Finally, to highlight the precision and versatility of this technique, two examples are presented next, in which it was used to study the temporal evolution of different materials that constitute part of port infrastructures. In the first, the short-term stiffening of soil subjected to an improvement treatment is verified. In the second, the long-term evolution of the natural ground under the fill in the platform of a maritime terminal is studied.

3.3.1 Short term

The Port Authority of Valencia conducted groundwork to increase the draft in the South Basin of the Port of Valencia. The project involved reinforcing dock foundations using jet grouting treatment in two phases at different locations. However, during the first phase, the leaning of caissons and differential movements occurred at the surface, prompting further monitoring. The main cause appeared to be differences in soil stiffness due to local strength loss during injection. Based on this problem, in the second phase of execution, it was considered to search for a method to investigate the evolution of the stiffness of the columns, especially at early ages, between hours and days. To fulfill this main objective, PS suspension logging was used innovatively (Tijera et al., 2023).

Figure 3 shows the results obtained for V_S in the tests carried out during the first hours after the injection of the jet.

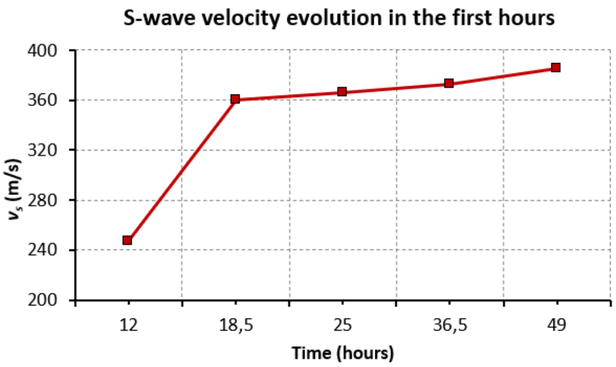

Figure 3. Obtained V_S values during the first hours after injection.

3.3.2 Long term

The study took place at the new container terminal of the Port of Cádiz, constructed using floating caissons and a closing dike. Hydraulic fills, mainly sands, were deposited on soft natural clays. Construction began in 2014, and in 2016, two boreholes were drilled for pressuremeter tests after an accelerated consolidation process. The boreholes were then protected with PVC pipes for the insertion of different geophysical probes. Since then, some PS logging measurements have been carried out at different times. The results are shown in Figure 4.

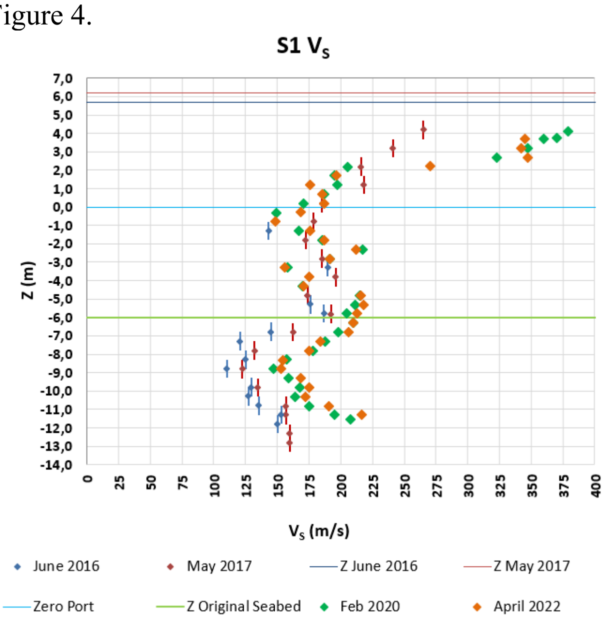

Figure 4. V_S values obtained at different times in one of the studied boreholes.

Even though the natural soil materials under the fill were undergoing a process of secondary consolidation from the beginning of the measurements, a slight increase in the V_S values could be observed. In Figure 4, the horizontal lines represent the height of the esplanade at different moments (red and dark blue), the zero level of the port (light blue), and the position of the original seabed (green).

4 CONCLUSIONS

The presented application cases have been chosen to demonstrate that the PS logging technique can be applied in studies with diverse objectives and showcase the main advantages of this technique: its versatility and precision.

Despite its great usefulness, its main drawbacks should not be forgotten: its high sensitivity to noise and the length of the probe.

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