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Automated simple tell-tale device for detecting loss of backfill soil through joints of quays

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ABSTRACT

Unlike most hydraulic structures, quays withstand high, bidirectional, and highly changing gradients. Thus, since discontinuities (joints in the former and gaps in the latter) are unavoidable when quays are engineered as concrete diaphragm walls or alignments of caissons, the backfilling soil in their vicinity is likely to be flushed out due to poor conditions of the joints at the wall face or of the sealing grout at the gaps. Soil loss may progress backward, causing eventually sinkholes on the yard pavement near the capping beam. The presence of unmapped growing cavities or "chimneys" beneath the pavement is even more hazardous for operating vehicles. The Laboratory for Geotechnics (Laboratoria de Geotecnia) (LG) at CEDEX devised the so-called "sand tell-tales": they consist of vertical short pipes (~ 1m long) refillable with clean medium-size sand, located halfway in potential erosion pathways, which initiate start near discontinuities. This new device allows for measurement of the loss of soil produced by previous inspection, in view of detecting incipient cavities. The combined analysis of all of them along the quay alignment leads to an overall assessment of the infrastructure. The purpose of this publication is to review the most important points of this elementary and innovative monitoring system.

KEYWORDS

Backfill Soil Loss; Sand Tell-Tale Device; Automated *Ad Hoc* Device; Quay Maintenance.

1. INTRODUCTION

As a part of the commission launched by Puertos del Estado for technical assistance, applied research and technological development in the scope of the state-owned port system, the Laboratory for Geotechnics (Laboratoria de Geotecnia) (LG) at CEDEX is involved, among other issues, in the detection of incipient cavities in a quay with a 750 m berthing line, which came into service in 2005.

For more than a decade, the corresponding Port Authority has periodically recorded the sudden episodes of metric sinkholes on the pavement near the cantilever beam, even though repair work has been carried out in the past. However, as a result of increased activity on the quayside in recent years, the occurrence of sinkholes has worsened.

The presence of unmapped growing cavities or "chimneys" occur suddenly because of a gradual process of upward washing of soil due to, firstly, poor conditions of the joints at the wall face or of the sealing grout at the gaps; and, secondly, to the high, bidirectional, and highly changing gradients withstand by the quays.

Since discontinuities (joints in the former and gaps in the latter) are unavoidable when quays are engineered as concrete diaphragm walls or alignments of caissons, it is important to have a simple tell-tale device for early detecting loss of backfill soil. In this way, it would be possible to warn the

occurrence of such unmapped growth cavities under the pavement and mitigate the operational hazard of working near the cantilever beam.

2. DESCRIPTION OF STUDIED QUAY

The structure of the studied quay is a 32 m long buttressed diaphragm wall of reinforced concrete, embedded in the seabed, leaving a berthing depth at -13 m. The diaphragm wall, built inland on an auxiliary approach embankment, consists of a series of "T-shaped" modules. The "T's" are 3 m wide and long and 0.6 m thick. These elements are anchored to a conventional passive concrete diaphragm wall (0.8 m thick) by means of two steel tie bars every module. The passive diaphragm wall also serves as a foundation for the rear crane rail for containers. The general cross section is depicted in the figure presented below. The edge beam has a service gallery and two front crane rails.

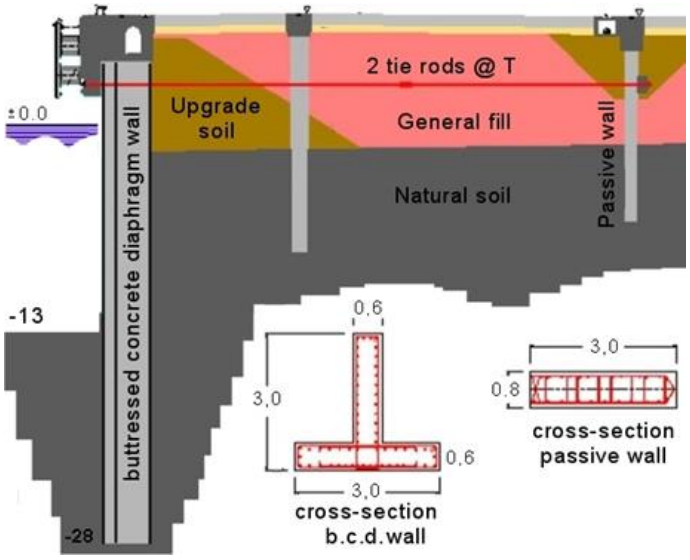

Figure 1. Cross-section of studied quay.

3. WORKS PERFORMED BY THE LABORATORIO DE GEOTECNIA AT CEDEX

To date, the LG at CEDEX has been in charge of completing a series of different tasks when collaborating with the corresponding Port Authority. Among them, gathering and analysing profuse historical documentation, during construction and subsequent reparation works, could be mentioned. Aditionally, the inspection of quays, using the Multichannel Analysis of Surface Waves (MASW) technique, geo-radar and the Panda penetration equipment (with its own staff) has also been a task performed.

Seeking for the prevention of the occurrence of backfill soil loss, the LG at CEDEX considered an essential task to detect incipient cavities. The main reason for this is that if cavities are not detected in time, water erosion can gradually conduct to backfill soil loss, producing the collapse of the corresponding zone of the quay (Figure 2), which could involve accidents with circulating vehicles. In this context, the LG at CEDEX was in charge of overseeing the "sand tell-tales" (refillable vertical pipes with medium-size sand where the loss of soil is measured), providing global assessment, together with previous inspection carried out by private companies, and, finally, a proposal for a specific inspection programme, both from surface and underwater. The following figure shows the erosion mechanism next to the edge beam.

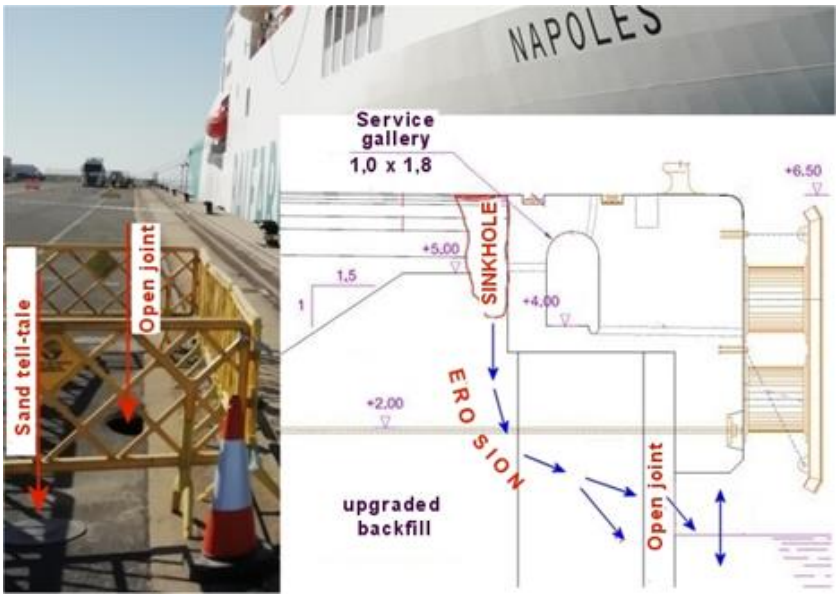

Figure 2. Erosion mechanism next to the edge beam.

4. SAND TELL-TALES DEVICES

4.1. Description

To deal with the sudden appearance of these sinkholes, in order to anticipate repair work and focus human and material resources on the most hazardous points along the 750 m berthing line of the quay, the LG at CEDEX designed the so-called “sand tell-tales” devices.

As it is shown in Figure 3, the sand tell-tale devices developed consist of short vertical tubes ~1 m long and 4" in diameter, refillable with clean medium-size sand, located halfway in potential erosion pathways, which are triggered in zones near discontinuities. Specifically, they are placed every 6 m on the pavement of the backside, at a distance of around 50 cm from capping beam (coinciding with a joint of the wall face in cross-section).

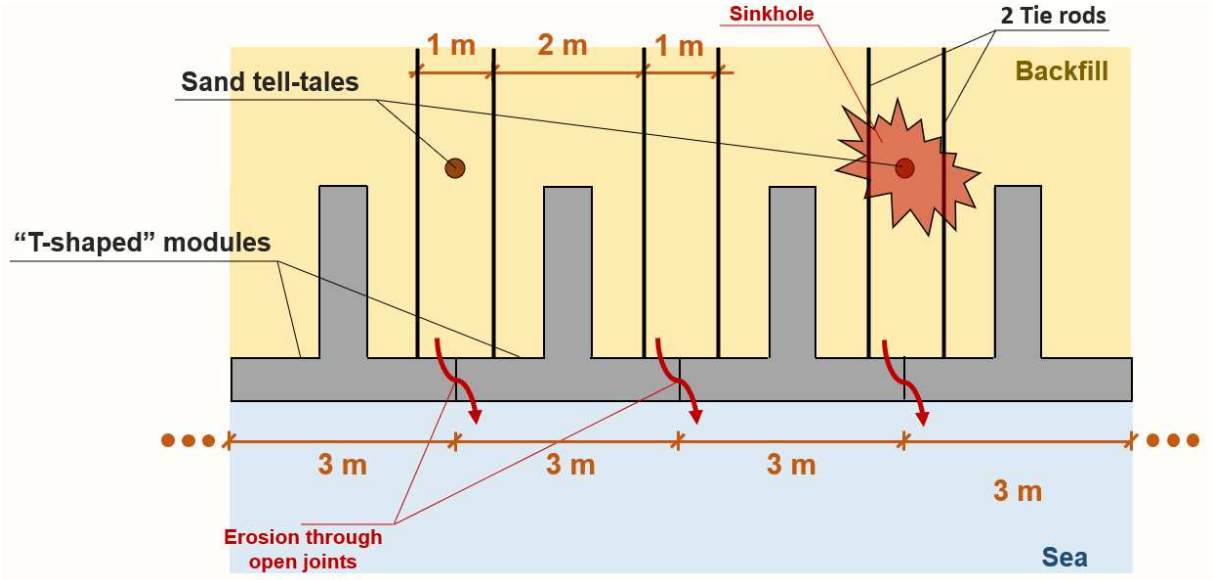

Figure 3. Detail of "T-shaped" modules of buttressed diaphragm wall and sand tell-tales devices in view of detecting incipient cavities.

The newly developed device allows the measurement of the loss of soil produced by consecutive inspections (two or three times a month), with the aim of detecting incipient cavities. The combined analysis of them all along the quay alignment leads to an overall assessment of the infrastructure. Details of a sand tell-tales device are shown in Figure 4.

Figure 4. Details of a sand tell-tales device.

4.2. Weaknesses and strengths of this *ad hoc* site investigation

Although the system is highly regarded for its utility, it falls upon conscientious workers to report soil erosion several times a month, the physical phenomenon of washing soil through the open joints occurs suddenly, and sometimes even faster than the time it takes to collect, store, process the data obtained into sand tell-tales devices and to make decisions. Consequently, it is very difficult to anticipate the repair works before the sinkhole occurs.

Motivated by the weaknesses observed in the *ad hoc* site investigation system designed, two improvements were implemented. On the one hand, a web form was designed and implemented associated with each sand tell-tales device and accessible via a QR code, thus facilitating the task of reading and automatically storing the data in real time, as well as its subsequent processing, analysis and graph export of the results and trends, minimising the time interval between data acquisition and decision-making (Figure 5).

Figure 5. App web accessible via-QR code.

On the other hand, due to the impossibility of carrying out very frequent data acquisition due to the existing human resources and the high activity level in the quay, this system will be complemented with the introduction of microprocessors with low-cost sensors in the most critical sand tell-tales devices (Figure 6). In this way, it will be possible to provide continuous records of the soil loss by Time of Flight (ToF) technology.

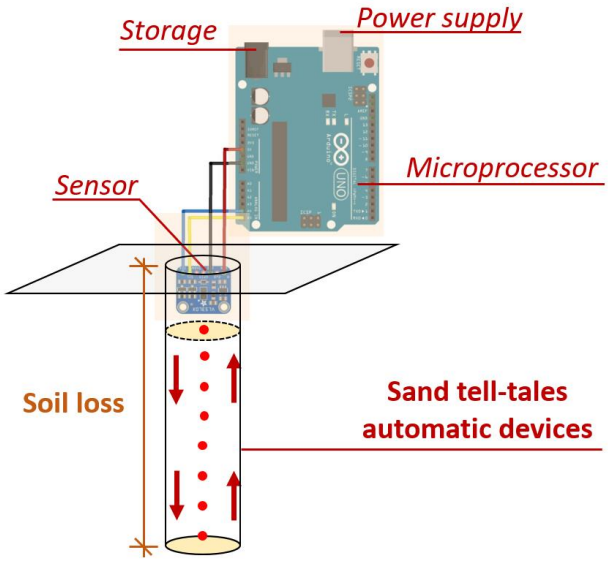

Figure 6. Sand tell-tales automatic devices.

The final product will allow the implementation of an early warning system on any mobile device of the Port Authority (Figure 7).

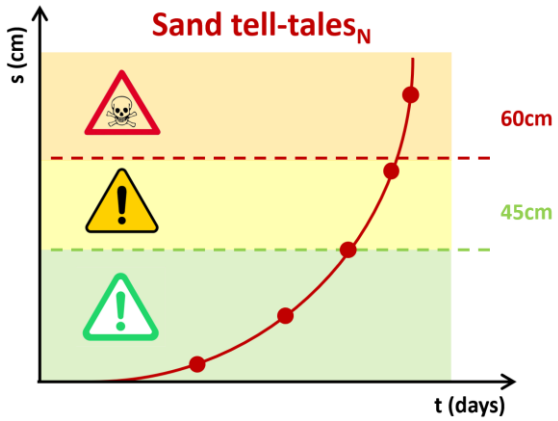

Figure 7. Real-time decision-taking tool.

5. CONCLUSIONS

Puertos del Estado is constantly recording the occurrence of sinkholes in quays belonging to different Ports along Spain, being this a common produced abnormality. Despite this fact, during the past few years, these type of irregularities have become more and more frequent, due to the increase produced in the activity developed in the quays. Considering that the occurrence of sinkholes could be prevented, it is of great importance their early detection, and further automatic treatment. In this context, the main objective of the presented research is to minimize the time between data collection in the field, its analysis and processing by a third party, and the decision-making by the infrastructure manager.

Bearing in mind which the main problematic was, an automated *ad hoc* device was proposed. The mentioned equipment consisted of two main parts. The first one, a sand tell-tale gadget, representing this the element in charge of indicating the occurrence of the backfill soil loss, provided of low-cost microprocessors, constantly recording lectures. The second part, consisted of a web form, which could be accessed through a QR code characterizing each sand tell-tale, in charge of showing the real-time data stored by the mentioned microprocessor.

The automated developed equipment has shown to be an all-in-all low-cost solution for preventing unmapped growing cavities in the port quays pavement, avoiding in this way, possible accidents. This fact is supported by the idea that the data acquisition is made in real time, being possible not only to get direct access to it with just having a mobile device, but also to make an instantaneous analysis of the results and consequent decision-making on how to proceed if needed.

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REFERENCES

Asanza-Izquierdo, E. 2019. Revisión histórica de estudios y actuaciones geotécnicas realizados en el Muelle Sur del Puerto de Huelva (2004-2018). *Informe Técnico Nº 5 para Puertos del Estado del Laboratorio de Geotecnia*, Madrid, España.

Laina-Gómez, C. 2022. Desarrollo y control de técnicas de auscultación geotécnicas, económicas y sostenibles, para estructuras costero-portuarias. *Jornadas I+D+i CEDEX 2022*, Madrid, España.

Laina-Gómez, C. 2024. Desarrollo y control de técnicas de auscultación geotécnicas, económicas y sostenibles, para estructuras costero-portuarias. *Memoria I+D+i CEDEX 2024*, Madrid, España.