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Research Paper

Numerical investigation into the failure of a micropile retaining wall

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A R T I C L E I N F O

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A B S T R A C T

The paper presents a numerical investigation on the failure of a micropile wall that collapsed while excavating the adjacent ground. The main objectives are: to estimate the strength parameters of the ground; to perform a sensitivity analysis on the back slope height and to obtain the shape and position of the failure surface. Because of uncertainty of the original strength parameters, a simplified backanalysis using a range of cohesion/friction pairs has been used to estimate the most realistic strength parameters. The analysis shows that failure occurred because overestimation of strength and underestimation of loads.

1. Introduction

A temporary micropile retaining wall with anchored tiebacks, which had been embedded in the ground before the excavation of an underground parking garage, collapsed after about 40% of the excavation had been completed [1]. The parking garage was a new addition to an old building that was being rehabilitated. Its construction required an excavation to an average depth of 16 m from the existing ground level, involving a total surface area of about 1400 m^2. Because of limited space for the parking garage between the old building and an amusement park it was not possible to safely slope the excavation sides. For that reason, a temporary retaining wall was needed before the actual excavation of the ground. The procedure is sketched in Fig. 1: first the temporary wall would be constructed embedded in the ground without much disturbance to the surroundings, then the excavation would start on one side of the wall and the tiebacks put in place. The excavation would continue by stages until reaching the required depth. This is a rather common technique for deep foundations of retaining systems which can be constructed using precast or cast-in-place diaphragm walls, bored piles or micropile systems of several types (secant, tangent, discontinuous). This technique first appeared in the 1950s [2] and has been developed and used in the past half-century not only for excavations but also for slope stabilization, ground improvement, underpinning of monuments, rehabilitation of historical structures, seismic retrofit, etc. [3–16]. The behaviour and failure of embedded or anchored *in situ* retaining walls has been extensively investigated as well in recent years [17–25]. A satisfactory performance of this type of structures requires sufficient knowledge of the geometric, topographic, hydrologic and geologic characteristics of the site, and of the material properties of the ground.

The original design of the case presented in this paper, specified a bored pile wall to stabilize the grounds of the adjacent amusement park. However, shortly before the construction began the design was changed to a micropile wall. This micropile wall eventually failed during the excavation.

After the failure, doubts were raised regarding several aspects of the construction process: ground characterization, design, construction issues and worthiness of the micropile/tiebacks system, effect of changing water conditions, etc. as possible causes of the failure.

Analysis of the construction logs and visual inspection of the site, especially the part of the wall that remained intact after failure, brought consensus between property, contractor and external consultants, that the construction of the micropile/tiebacks system had been properly executed according to design specifications. This was further justified with a in-situ load test performed by an independent contractor on a newly cast micropile of the same type used in the failed wall. This load test showed that the pile performed well within the strength parameters specified in the design.

Also in question was the true position of the water table at the moment of failure, since there was evidence from precipitation

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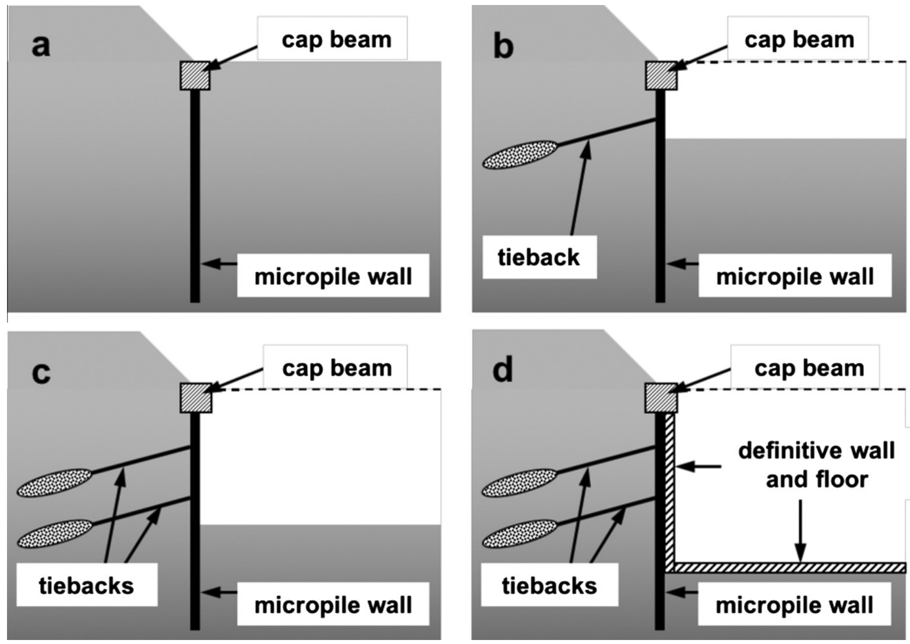

Fig. 1. Schematic sequence of the excavation: (a) execution of the micropiles; (b and c) intermediate stages including excavation and execution of the tiebacks; (d) final state.

records and instrument readings in the area that the water table could be located near the surface after intense rainfall. However, records of rainfall accumulation during the days preceding the collapse show that rain episodes on those days were minimal. Seepage induced from leakage of a nearby water tank is considered irrelevant because the small volume of water involved could not significantly change the position of the water table. Therefore, it seems unlikely that the water table had moved to near-surface levels at the time of the wall's failure and, in any case, the micropile wall that had been constructed was in essence "discontinuous" and consequently completely permeable during this temporary construction stage. Water pressures on the wall would then be automatically cancelled. Similarly, seepage forces were unlikely to play a significant role if the water table was not near the surface. If that had been the case, the seepage regime would have been quite complex and further study would be needed. Finally, assuming that the water table did not change its position in the days preceding the failure, there could be no reduction of effective stresses and loss of shear strength because loss of suction [26–29] as the degree of saturation increases.

After ruling out poor construction techniques and water effects as direct causes of the failure, there remained ground characterization (both geotechnical parameters and topography), and design of the wall based on the information available about the site conditions as main suspects. These were the issues left to further investigate the causes of failure and establish proper responsibility. It was decided to perform a numerical analysis to simulate the failure process with the design ground topography and with the actual ground topography, to establish the most likely failure scenario and to determine the quality of the ground parameters used in the design.

The numerical analysis had to provide answers to the following: (a) whether the wall could fail with design strength and with design topography; (b) whether the wall could fail with design strength and with actual topography; (c) if the answer to the previous questions was negative, repeat the analysis with the actual topography and with a range of strength parameters of smaller values than the design ones, until failure was reached. The strength parameters for which failure is predicted are the most likely actual strength parameters of the ground. The numerical analysis also provides the shape and position of the failure surface.

It will be shown that the failure of the micropile wall can be attributed to a poor and incomplete knowledge of the ground's geotechnical properties and a lack of detail of the topographic data (see Figs. 3 and 4) which led to an overestimation of strength and an underestimation of the loads carried by the wall and tiebacks.

2. Location and geological data

The location where the failure occurred is a hill near Barcelona, Spain. It has an irregular rounded triangular shape (Fig. 2), with a total surface area of approximately 6000 m^2. The topography is determined by its location near the top of a hill which is at the SE end of the coastal range that runs approximately parallel to the coast and is formed by a sequence of low-height ranges. The lithology units outcropping in the range are the oldest in the area, consisting mainly of meta-sedimentary Palaeozoic rocks, especially

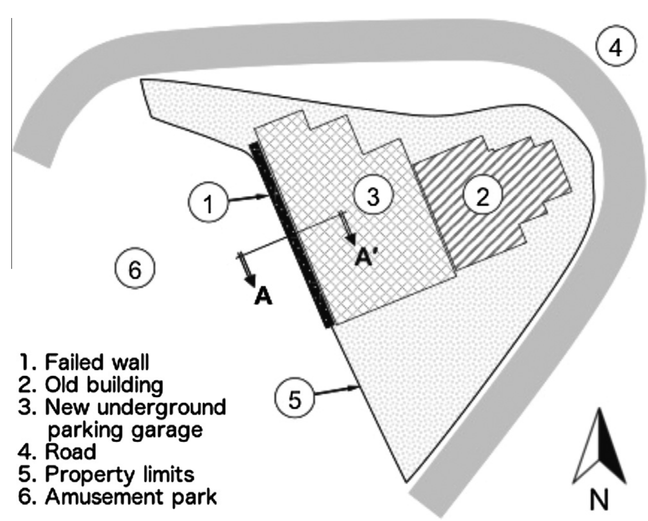

Fig. 2. Sketch of the area showing the original position of the collapsed wall. Section AA′ is shown in Fig. 5.