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Micropiles for building foundations on karstic areas

Les micropieux pour les fondations d'immeubles dans les régions karstiques

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SYNOPSIS: For the foundations of ten storey buildings in certain areas in Mallorca, where the ground consists of karstified calcarenites, the micropiling technique has been used with satisfactory results from both technical and economical points of view. The paper describes the ground conditions at the sites and analyzes the possible foundation solutions. The design criteria for the micropiles and the construction details are given. A load test on an instrumented micropile was carried out in order to check the validity of the design assumptions. The load test is described and its results discussed.

1 INTRODUCTION

Founding buildings on karstic rock is a complex task. Most of the available solutions are quite expensive and, hence, the cost of the foundations can represent an important part of the overall cost of the buildings. Some of the usual solutions are not safe enough or are based on uncertainties.

KRONSA has applied the micropiling technique to solve this problem, with very satisfactory results from both technical and economical viewpoints.

The paper describes this new solution and analyzes the results of a load test on an instrumented micropile, carried out in order to obtain design parameters for the particular site conditions.

2 GEOLOGICAL CONDITIONS. SITE INVESTIGATION

Large areas in Mallorca are covered by Miocene deposits consisting of karstified calcarenites dated as Helveniense-Tortonien (fig. 1). The rock frequently shows a complex pattern of interconnected cavities of variable size. The most eloquent example is represented by the "Drach Caves", one of the touristic attractions of the island.

Jaume (1987) studied the continuity and distribution of the karstic system. By considering the structure originated by bedding and joint planes as well as the variability of the rock itself, he concludes that the distribution of the cavities is highly heterogeneous and, hence, no accurate mapping of the karstic system is feasible.

The experience gained in this type of ground has led to a rapid and effective site investigation method. A few boreholes with core recovery are first performed, each one located near the axis of one of the building columns. Percussion drilling without core recovery is then carried out on the location of each column. A continuous record of the input energy and type of detritus is performed. Ground identification is then made by correlating the results of both types of boreholes.

This simple technique provides information on the ground profile under each column and, specially, on the existence of cavities below them, but no information is obtained on their shape and lateral continuity. The ground characterization is made by means of the following qualitative descriptions:

- Intact calcarenite
- Fissured calcarenite
- Weathered calcarenite
- Highly weathered calcarenite
- Cavity filled with fines
- Empty cavity

Laboratory tests carried out on intact rock samples have given the following results:

- Dry specific gravity: 19 kN/m³
- Unconfined compression strength: 35 MPa
- Deformation modulus: 35,000 MPa
- Poisson ratio: 0.14

The water table is located slightly below the ground surface. Simple pumping tests carried out in the investigation boreholes have revealed an extremely high permeability. Actually, no depression of the original water level was observed near the tested boreholes.

Fig. 2 shows the results of some contiguous boreholes corresponding to one site. It is obvious that any lateral extrapolation of the ground profile can be considered as guesswork. As an example, fig. 3 shows two possible interpretations of these results. If fig. 3(a) gives the right answer, the selection of shallow footings could lead to a dangerous situation. Contrarily, should fig. 3(b) represent more appropriately the ground profile, shallow footings would be a safe solution.



Figure 1. Location map.

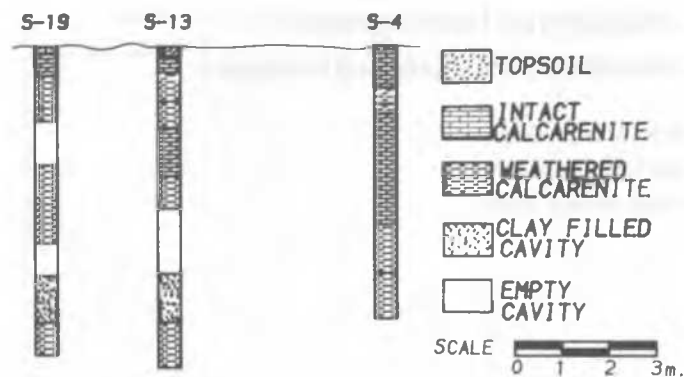


Figure 2. Typical borehole logs.

3 FOUNDATION DESIGN. ANALYSIS OF SOLUTIONS

The micropiling technique has been applied to ten storey buildings with reinforced concrete structure and column spans from five to eight meters. Some of the column loads are of the order of 3.5 MN.

The main problem that has to be faced in the design of the foundations is the existence of large cavities at various levels, even at shallow depths. After analyzing the ground profile under each column, ordinary footings are disregarded due to the high risk of a fragile failure of the rock.

In order to avoid such a risk, several solutions are usually applied in cases of karstic ground.

3.1 Rigid raft foundation

It is a good solution in some instances. The average foundation pressure being small, the cavities can be bridged if they are relatively small too. However, the design is very complex. The ground pressure distribution under the raft is unknown and so are the bending moments and shear forces. The stiffness criterion leads to large raft thicknesses and costly reinforcements. The solution is very expensive and of uncertain safety.

3.2 Continuous beams grid foundation

An alternative to the raft foundation is a grid of continuous beams. The design complexity is similar but it is easier to consider reasonable hypotheses about the ground response. A regular column grid is advisable. This solution has been successfully

applied to some three storey buildings. For the design of the beams, the assumption was made that the beams should withstand the load of any column with a free span equal to twice the distance between adjacent columns. It is also an expensive solution but still adequate for low buildings.

3.3 Bored piles

The installation of bored piles in rock is very expensive and time consuming. In addition to the cost of drilling, the presence of empty cavities poses a complicated problem of casings or forms in order to retain the concrete.

If the load carrying capacity of the pile is to be fully used, a sufficient degree of certainty of the non existence of cavities below the pile base has to be achieved. Once a certain depth has been reached a borehole has to be drilled from the bottom. If a cavity is detected, it is then necessary to proceed with the excavation and the operation has to be repeated. Nevertheless, a borehole does not fully guarantee against the risk of existence of a cavity below the pile base.

3.4 Grouting

Filling of the cavities by means of grouting constitutes a clear temptation, but this solution has very important drawbacks. First of all, the fines filling partially or totally most of the cavities should be removed. Otherwise, the risks do not disappear. Secondly, the voids have to be entirely filled with grout, which is really difficult, particularly at the cavity roof, in order to avoid a vault failure. Thirdly, limitation of the volume to be grouted is almost impossible in a well developed karstic system and, consequently, enormous amounts of grout can be spent without success. Finally, the control of the results is uncertain.

This solution is very expensive and not safe enough. It has been tried by others with very bad results in one site near the ones where the micropiling solution has been used. After spending a lot of time and money, grouting was abandoned.

3.5 Micropiles

This solution is based on the installation of micropiles contrived to work only along their shafts. The contribution of the base is disregarded thus accounting for the possible existence of cavities below it. The application of this type of solution is described in the following.

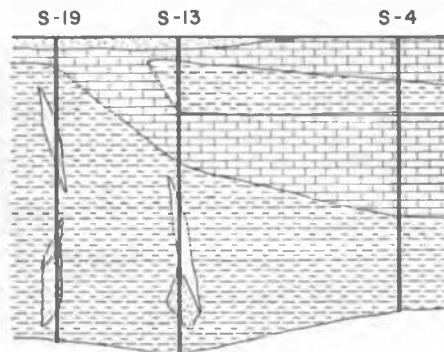
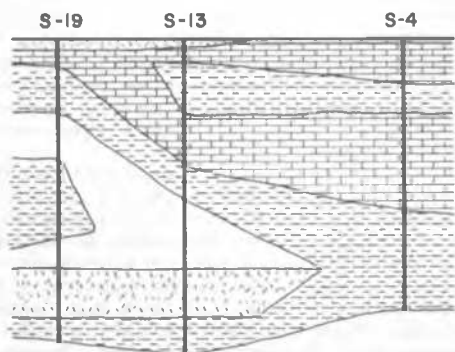


Figure 3. Interpretation of results.

4 MICROPILES SOLUTION

Drilling of the boreholes for the micropiles is carried out with the same equipment previously used in site investigation. Therefore, this operation provides the ground description mentioned above, i.e. existence and location of filled and empty cavities, quality of the rock mass, etc.

Table 1 shows allowable shear stresses assumed on the ground-micropile interface as a function of the ground description. Since the settlement required to mobilize the assumed shaft resistance along intact rock and the elastic compression of the micropile itself are small, no shear mobilization along compressible ground takes place.

The length of each micropile is then determined in situ by considering the results of its corresponding borehole. Drilling is stopped when sufficient shaft resistance is achieved to withstand the design load of the micropile. This is done by simply considering the values shown in Table 1 and the previously selected diameter of the micropile. In the case of shallow cavities, the resistance of the ground above them is disregarded. Sometimes, consideration is given not only to the results of the borehole corresponding to a particular micropile but also to those of the adjacent ones.

No account is taken of the contribution of the micropile base to its overall bearing capacity. Therefore, undetected cavities closely below the base of the micropile have no influence on the calculations and safety of the foundations unless they are relatively large. As an exception, if a large cavity is found during site investigation below any of the building columns, a special analysis of the situation is carried out and appropriate measures are taken in the design.

Fig. 4 shows a typical section of a micropile.

Table 1. Allowable shear stresses

Ground description	(kPa)
Intact calcarenite	300
Fissured calcarenite	200
Weathered calcarenite	100
Highly weathered calcarenite	---
Cavity filled with fines	---

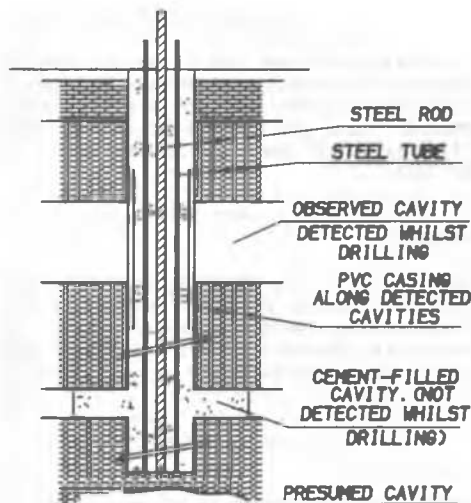


Figure 4. Section of a micropile.

The reinforcement generally consists of a steel tube and a varying number of steel rods which depend on the designed axial load. Once the reinforcement has been installed in the borehole, a mortar with plastifiers is grouted from the bottom by using a tremie pipe placed inside the steel tube.

Empty cavities are sealed before grouting by means of PVC pipes but, occasionally, some small ones remain undetected. These cavities are eventually filled with an extra volume of grouted mortar. In the case of cavities filled with fines, the drilling process gives rise to a localized increase in the diameter of the micropile. It results in an extra consumption of mortar but the bulb formed along such a cavity has a beneficial effect on the load transmission.

If a micropile crosses an empty cavity, special attention is given to prevent buckling effects. As a general rule, the standard reinforcement shown in fig. 3 has proved to be safe enough for cavity heights of the order of 2 m. For heights greater than 2 m, an extra reinforcement is required.

5 LOADING TEST

A load test on an instrumented micropile was carried out in order to check the validity of the design assumptions and to obtain representative values of the shear resistance along the micropile shaft for the different rock qualities.

Fig. 5 shows the reaction system used for the test. The load was applied with a hydraulic jack and the reaction was provided by three anchors.

The load test instrumentation consisted of:

- 3 micrometers (accuracy: 0.01 mm) to measure settlements of the micropile head.
- 10 strain-gages (resistance: 120 Ω ; factor gage: 2.1; length: 1 cm); placed on the steel tube of the micropile at regular intervals. Actually, only those located at 1.3, 2.3, 3.4 and 6.0 m depth worked properly.
- Oil-pressure gage (accuracy: 1 Pa).
- Wheatstone bridge (accuracy: 1E-6 in terms of strain).

Fig. 6 shows the ground profile deduced from the borehole of the tested micropile.

The micropile had the following features:

- Length: 6.5 m.
- External diameter: 220 mm.
- Steel tube: External diameter: 100 mm.
Internal diameter: 80 mm.
Strength: 340 MPa.
- Mortar strength: 40 MPa.

The bottom of the borehole was filled with a highly compressible material. This simulates a cavity below the micropile base.

The design load, according to the assumed shear stress criteria given in section 4, was 400 kN. Four load-unload cycles were carried out, as shown in fig. 7, where measured settlements are plotted. The test was stopped at a maximum load of 800 kN. Neither bearing capacity failure nor excessive settlements occurred under this load but, regrettably, a slight eccentricity between the jack and the micropile head led to bending of the latter.

Each load step was applied after settlements stabilized under the previous one. Three readings from the micrometers and two readings from the strain-gages were taken for each load step.

Fig. 8 shows calculated loading levels vs. depth as a function of the applied load, deduced from the assumed deformability characteristics of the micropile materials and the measured strains.

A limiting adhesion of 1 MPa was measured in a lab. test for the sound rock-mortar interface.

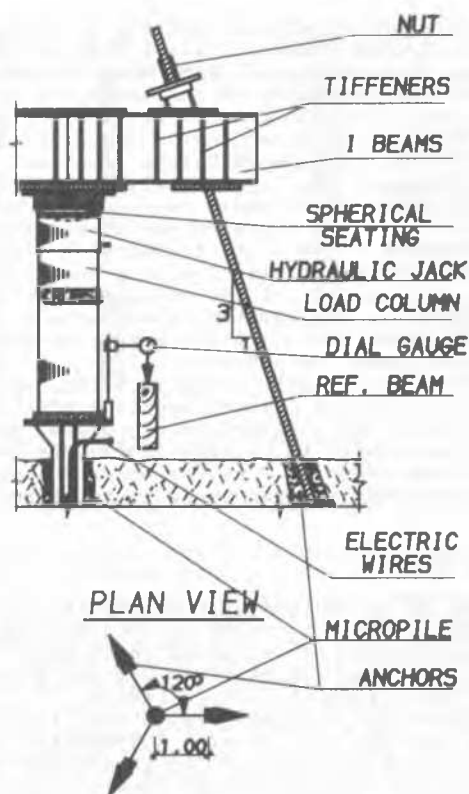


Figure 5. Multiple ground anchor reaction system.

6 DISCUSSION OF RESULTS

Measured settlements were less than 5 mm for the maximum load (0.8 MN, twice the assumed service load) and less than 2 mm for the design load.

Test results reveal that shear stresses concentrate mainly along the intact rock levels, though weathered zones also sustain some load. Assumed allowable shear stresses should be as follows:

- Intact calcarenite: 500 kPa
- Fissured calcarenite: 300 kPa
- Weathered calcarenite: 150 kPa

Bending of the micropile head at the end of the test took place along a thin layer of superficial, loose residual soil (terra rossa), as a consequence of a slight eccentricity of the applied load. However, under normal working conditions superficial buckling is prevented thanks to the concrete bracing-beams which connect contiguous caps of micropile groups.

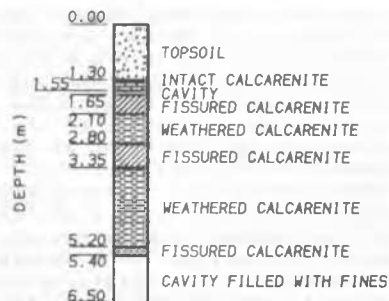


Figure 6. Interpreted ground profile.

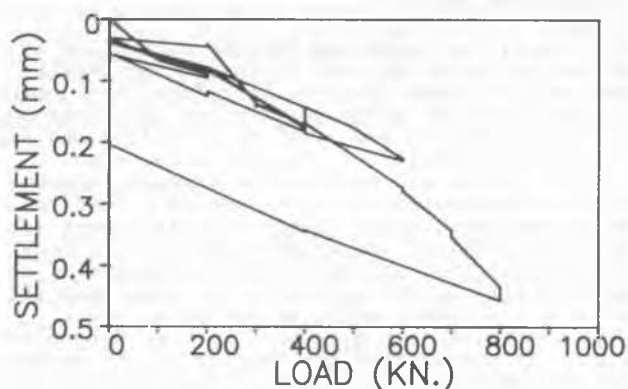


Figure 7. Load-Settlement plot.

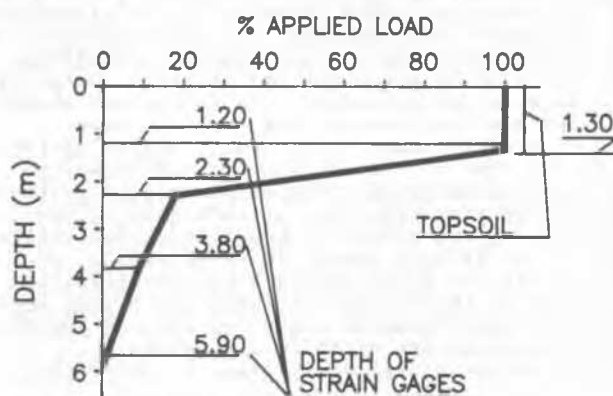


Figure 8. Loading level at depth.

7 CONCLUSIONS

Micropiling has proved to be a very satisfactory and economic way of foundation design and construction on karstic areas in Mallorca (Spain), mainly consisting of calcarenites. From a technical viewpoint, this approach is quite simple and is not subjected to the uncertainties which derive from other methods such as cave-grouting or raft foundations.

Unless very large cavities are detected during site investigation, the micropiling method can be applied in a systematic way and the cost of the foundations can be very approximately known beforehand (this is certainly not the case of the grouting technique).

8 ACKNOWLEDGEMENTS

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REFERENCES

- Jaume, G. (1987). Geological Formations in Sa Coma (Mallorca). Personal communication. (In Spanish).