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PRECAST CONCRETE PILES AND DRILLED PILES IN CARSTIC LIME STONE

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Contents

Summary

Some years ago the construction of a cement factory in the near of Hanoi was started. The factory and its five silos were to be founded on precast driven piles. During the piling work, the piling records showed that the normal stop criteria could not be fulfilled. Therefore new types of piles were suggested.

The soil consists of 20 m soft soil layers on limestone. The limestone is fractured, weathered, full of carstic cavities and is in some parts of the construction site much inclined.

Eight load tests on three different types of piles were performed to get a solution of the problem: the common precast concrete pile 30 x 30 cm with or without rock shoe, a small hollow pile 35 x 35 cm with the hole ϕ16 cm and a great hollow pile with an outer diameter of 55 cm and an inner diameter of 39 cm. According to the rock conditions, the result of the load tests and calculations, new criteria for design of piles were proposed. The common piles with rock shoe are used in the area of sound rock in small inclination. In the area of small cavities, fractured and steep sloping bedrock the hollow piles 35 x 35 cm are driven. In the case of the cavities with large dimensions and the height is more than 3.0 m the great hollow piles are used. After driving the hollow piles onto the rock surface, a hole is drilled into the bedrock and a steel rod is driven to bottom of the drilled hole. The connection between the steel rod and the concrete pile is made by grouting. By means of the steel rod, the load is transferred to the bottom of the cavities, to deeper homogeneous strata, to prevent sliding of the piles. The hollow pile ϕ55 permits the use of greater steel rods to reach the bottom of the cavities, to take large load and to avoid buckling.

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Nguyen Truong Tien

Introduction

Carstic limestone causes special problems for pile foundations, especially in the case of heavy structures. The extent of cavities and faults present uncertainties for the safety of pile foundations. In this report two types of hollow precast concrete piles and their use in compound with drilled steel rods into bedrock for foundation of five cement silos and several additional items in the north of Vietnam are presented. The foundation of the structure caused several problems due to the nature of the bedrock, limestone in steep inclination and fractured. The limestone is overlayed by 20 m soft soil deposits and top fill material. The silos have a base diameter of 16 m and are placed with 18 m axial distance. The total weight of the five silos is 95,000 tons.

1. Geology and rock conditions

1.1 Soil investigations

The soil profile is presented in Table 1, where some properties of the soil are collected. Under the fill of 2 m., two layers are generally found. The first consists of 5-9 m greyish, fine grained sand and under it the other of 5-10 m yellow or reddish yellow clay partly mixed with sand and gravel. Vane bore tests were performed at the site and laboratory tests were made on the samples taken. Fig. 1 shows a typical result of static sounding. All results of the field investigations and the laboratory tests made it clear that the foundations could neither be founded on the soil nor could they be supported by friction piles, they had to be supported by point bearing piles onto the limestone bedrock.

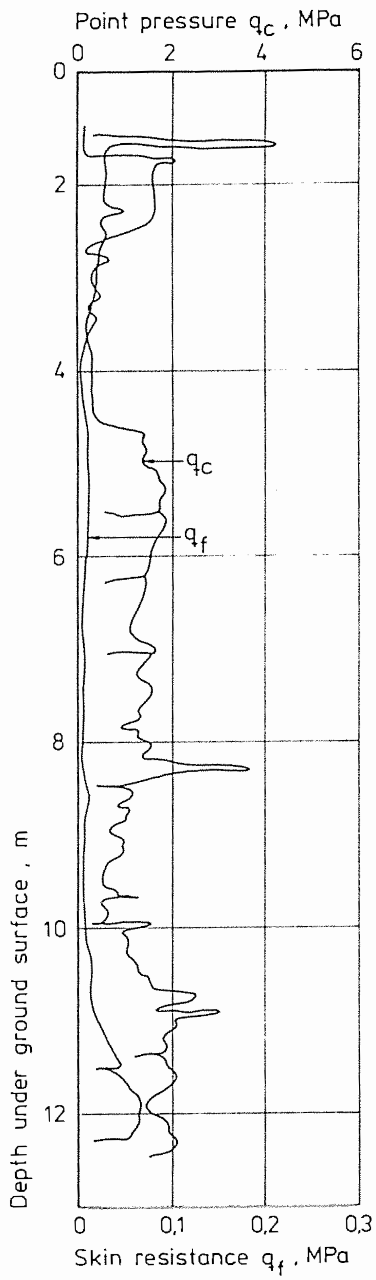

Fig. 1 Typical result of static sounding.

TABLE 1. Results of soil investigation

	Fill material 2 m	w_n = 40-90%; γ_o = 1.5-2.0 t/m^3 n = 0.30-0.35; e_o = 0,5-0.6
	Fine grained sand (5-9 m)	w = 17.8-28.4%; γ_o = 1.77-1.91 t/m^3
	Yellow or reddish yellow partly mixed with sand and gravel (5-10 m)	w_n = 41.9-55.6%; γ_o =1.84.2,3 t/m^3 γ_d = 1.1-1.4 t/m^3; γ_s =2,6-2.8 t/m^3 n = 0.45-0.57; e_o =0.9-1.35 w_L = 45-54%; w_p =27-34% $\tau_{fu,v}$=30-150 kPa
	Limestone with cavities	

1.2 Rock conditions

Drillings down into the bedrock were made for the detection of cavities. With the information collected, it was possible to reproduce the bedrock surface and its cavities. A typical cross section of the bedrock is given in Fig. 2. The limestone is fractured, weathered and full of carstic cavities. The dimensions of the cavities are 0.5 to 9.0 m. The cavities are either filled with clay mixed with sand or partial empty. The clay in the cavities is of the same type as the covering clay. It is therefore most likely that the clay filled cavities have an opening through which the clay can intrude.

The compressive strength of the rock was evaluated from cylindrical samples. Samples from different boring cores were tested. The unconfined compressive strength of the limestone is shown in Table 2.

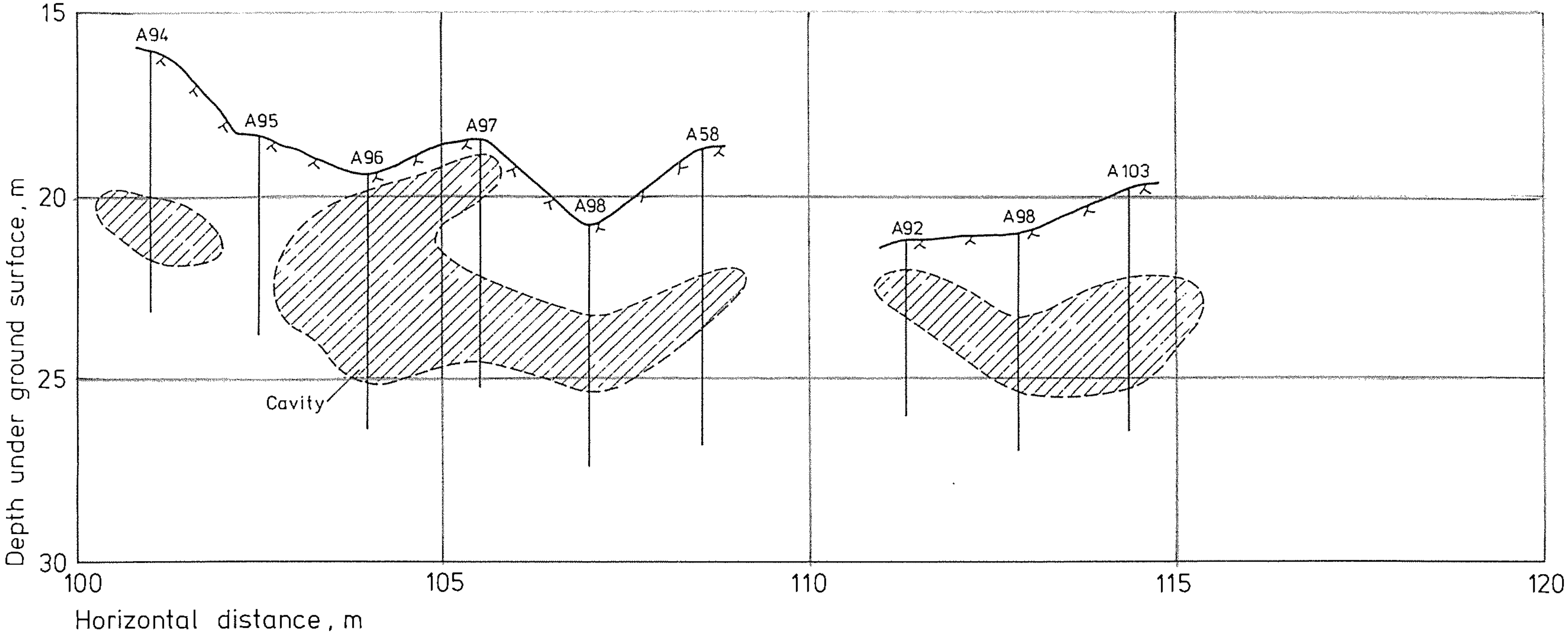

Fig. 2 Cross section of the bed rock.

TABLE 2. Compressive strength of the limestone.

No of sample	Diameter of sample (cm)	Ultimate load (kg)	Compressive strength kg/cm^2	Boring core %
IA	11.40	22.000	215.40	<20
IB	10.80	20.000	223.80	
IIA	11.60	30.000	288.70	20-50
IIB	11.40	27.000	264.60	
IIIA	9.0	99.500	1093.10	>50
IIIB	9.0	125.000	1966.00	

2. The foundation problems and their solution

The cavities, the steep inclination of the rock surface and the fracture of the bedrock caused several problems in the design and the construction of the pile foundations. The main goals for the foundation were

- the safe embedment of piles in the bottom of cavities of different dimensions.
- the heaving of the piles after previous driving and the driving criteria for piling work for the limited capacity of pile hammer.

2.1 Solution of the case of a small cavity, steep inclination and fracture of the bedrock

When the inclination of the limestone surface was more than 40^{o} the operation for the construction of each pile was as follows: the 35 x 35 cm precast concrete hollow pile with a hole of ϕ16 cm was driven to the rock surface, whereafter a hole was drilled 50 cm into the bedrock. A steel rod was mounted in the hole as a connection between the concrete pile and the rock and cement mortar was injected through the hollow pile and thus firmly anchored the pile to homogeneous rock. In Sweden hollow piles are used but the diameter of the hole is 60 mm. The diameter of the hole of 160 mm in this case was due to the condition of manufacturing the piles and to the equipment for drilling.

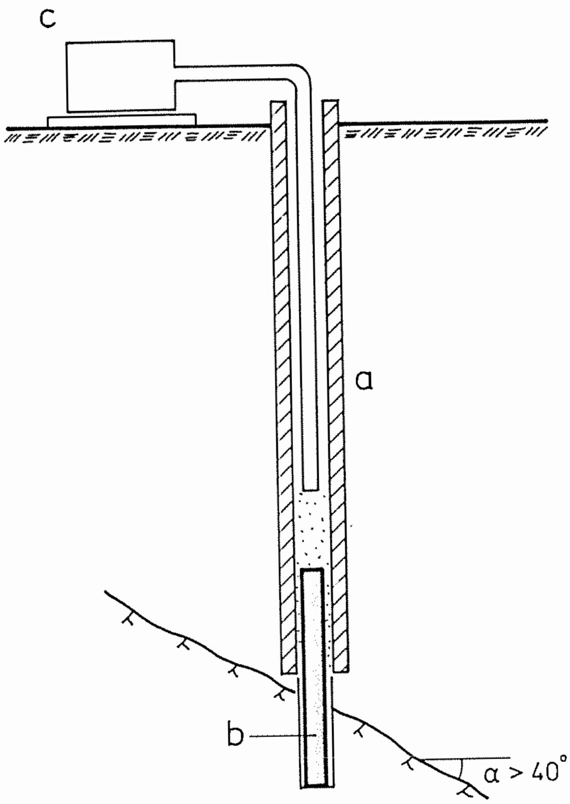

Fig. 3a Small hollow pile for the case of steep sloping bed rock ($\alpha > 40^{o}$)

a = precast concrete pile

b = steel rod

c = injection equipment

In case of fractured and weathered bedrock the previous procedure is performed, but the depth of the drill hole into bedrock is increased to 1-2 m depending on the quality of the rock. The steel rod then transfers the load to the sound rock. The same procedure has been described by d'Appolonia et al (1975) for cast in situ piles.

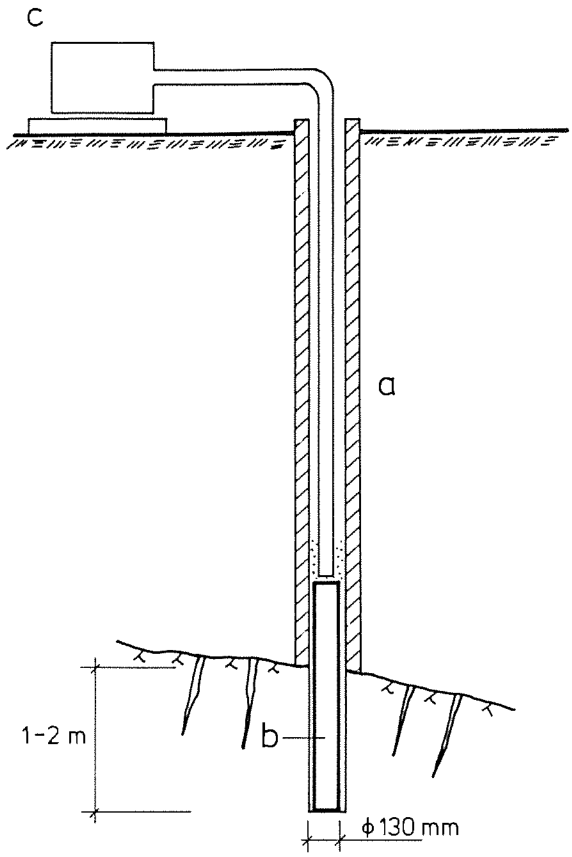

Fig. 3b Small hollow pile for the case of weathered bed rock
a = precast concrete pile
b = steel rod
c = injection equipment

In case of cavernous conditions the concrete piles are driven to the rock surface and a hole is drilled through the cavity or cavities into solid rock. A steel rod is mounted on the bottom of the drilled hole and reaches minimum 1 metre up into the hollow pile. The steel rod (ϕ110-120 mm) is driven to the bottom of the drilled hole by the same procedure described by Bredenberg and Broms (4). The hole of the pile

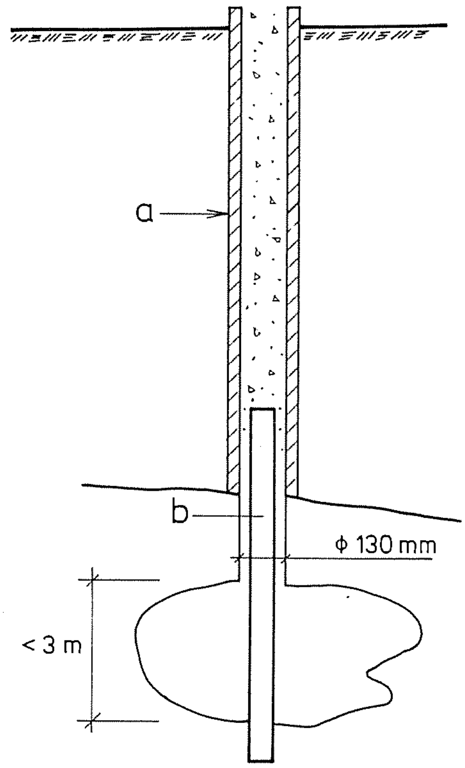

Fig. 3d Small hollow pile for small cavities,
a = precast concrete pile ϕ160 mm
b = injection equipment, injection at low pressure

is then cleaned by air pressure and water, whereafter the cement mortar is injected into the cavities and into the hole of the pile. The pile is designed to take a load of 700 kN, and the steel rod can only reach the bottom of the cavities of maximum 3 m height. In some cases the grouting is performed without having the steel rod mounted. This pile is designed to take a load of 400 kN (see result of Test pile No 7).

In Fig. 3 the design of the small hollow pile (35x35 cm) and its application for different purposes is shown.

2.2 Solution of the case of a big cavity

As the height of cavities in some cases is more than 3 m the small hollow pile cannot be used due to the problem of stability. A greater type of hollow pile is thus recommended in these cases. This type of hollow pile is cylindrical with an outer diamter of 55 cm and an inner diameter of 39 cm. The advantage of this pile is that it can take 2-5 times larger load (1750 kN) than the smaller pile. The cylindrical hollow pile permits the use of a greater steel rod with greater possibility of reaching the bottom of great cavities without buckling of the steel rod. The steel rod is compounded by a steel pipe or steel profiles. The operation for the construction of each pile then follows the same procedure as described in the previous section.

In this case a hole of 300 mm diameter is drilled into the bedrock for detection of cavities and makes the extension of concrete pile possible by mounting a steel rod at least 1.0 m below the cavity. The steel rod extends more than 2.0 m inside the concrete pile and is driven by means of a hammer of 3.5 tons.

To reinforce the connection between the steel rod and the concrete pile a steel net is mounted in contact with the top of the steel rod before grouting. Fig. 4 shows the cylindrical hollow pile with the steel rod. The grout used consists of a cement sand/water mixture in proportions depending on the discontinuities and the cavities of the rock. The relation between cement and water is in general 0.4-0.5. Grouting is done from the bottom of the hole to the top by means of an inserted pipe. To avoid large losses of grout the grouting is performed at low pressure. Sitoropolous et al (8) have obtained good results in performing low pressure grouting. The design of a mixed concrete and steel pile follows common procedures of steel and

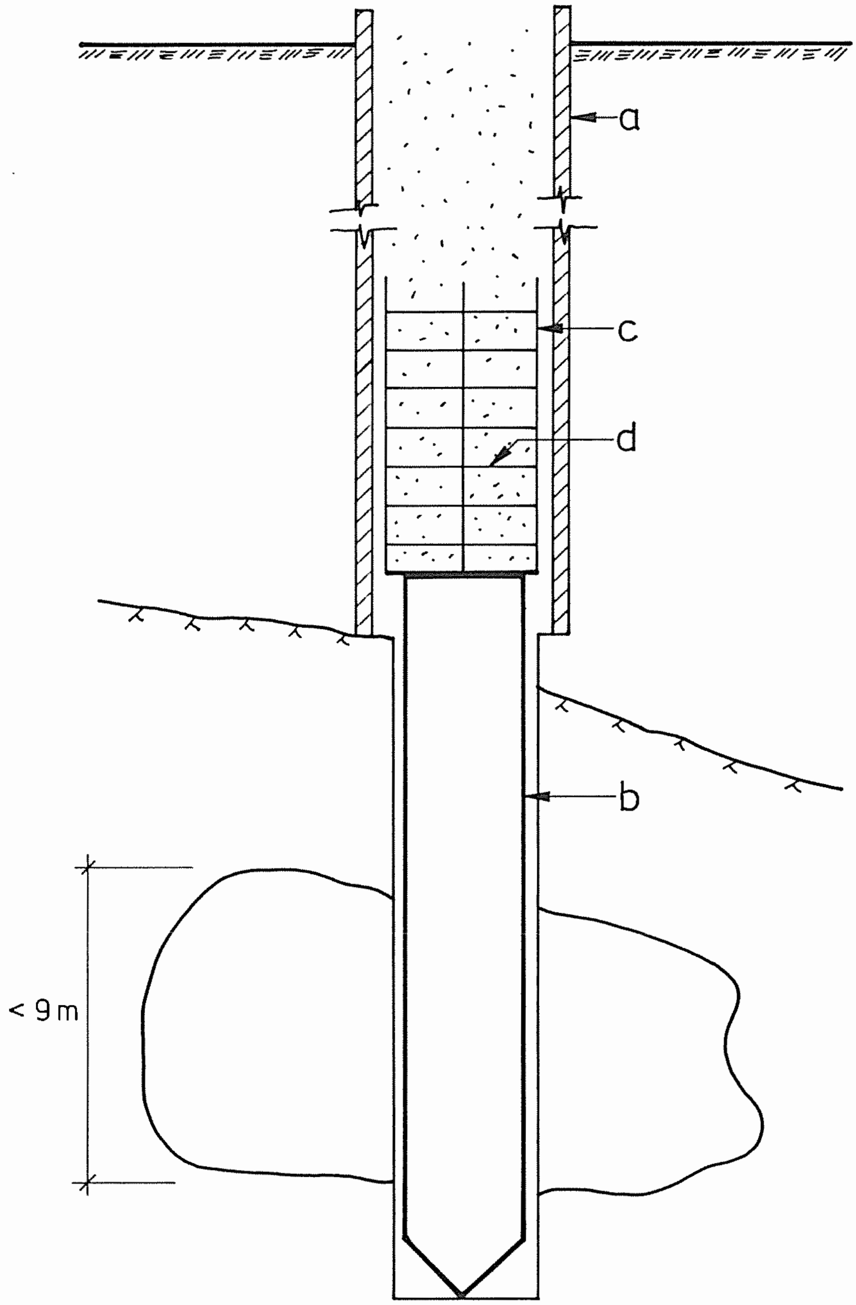

Fig. 4 Great concrete pile and steel pile

a = precast hollow concrete pile ϕ = 550 mm

b = steel pile

c = steel reinforcement bars ϕ32 mm

d = steel reinforcement net

concrete structures (2, 5, 6). The buckling load of the steel rod is checked, the upper end being fixed in the concrete pile and the lower end pinned into the rock.

The compressive strength of the grout is 20-25 MPa and the cohesion between steel rod and grout in similar condition is 1.5 MPa.

In the two applications (2.1 and 2.2) the hollow piles are used as boring tubes in the drilling work and also as a casing in the concrete work.

Based on the soil investigations and rock conditions the pile plan for every silo is designed. The hollow piles are used for silo 2 and 3. The small hollow pile (35 x 35 cm) and common pile (30 x 30 cm) are used for silo 4 and 5. Totally 700 small hollow piles and 80 great are used.

2.3 Redriving of piles and pile driving criteria

At the beginning of the piling work it was noticed that the piles heaved when driving neighbouring piles. Thus all the piles should be redriven. The procedure of redriving followed the recommendation of the Swedish Building Code 1975 (5). The heaving of the piles is due to displacement of surrounding soil. In some cases the heaving of a pile reached a value of 8 cm.

Since the piles were driven by a diesel hammer it was necessary to reduce the drop height in order not to damage the piles driving them onto rock. The pile driving criteria is 10 mm of penetration for the 3 following series of 10 blows with a drop height of 0.8-1.0 m. The load test of the pile No 4 shows that the driving criteria is satisfactory.

3 Load tests

Eight load tests are performed for different types of piles and rock conditions. The first pile was a common pile without rockshoe and driven onto solid rock. The second and third piles were common piles (30 x 30 cm) with rockshoe and driven onto fractured, weathered rock. Four small hollow piles (35 x 35 cm) were tested. Pile No 7 is designed for only 400 kN. Load test No 8 made on the greater hollow pile (55 cm) without steel net to reinforce the connection between the concrete pile and the steel rod. A summary of the test results is presented in Table 3. The load test curves are shown in Fig 5.

All the load tests were performed at the short term test. The load was applied in increment of 5 tons and 10 tons, the minimum duration of each increment was 5 min. The load was increased when the axial deformation was less than 0.05 mm/min. The piles were unloaded, after the load the first time had reached 50, 100, 150, 200, 250 and 300 tons. The failure load (bearing capacity) has been taken as either the peak load or the load when the axial deformation of the pile suddenly started to increase (3).

The result of load test No.1 shows that the pile has a low bearing capacity. This probably depends on that the pile point tip is very small consisting of only a steel pile $\phi 40$ mm and a steel rod $\phi 32$ mm in the center. The point tip therefore can be destroyed during the piling work. The contact area with the rock surface is small and therefore causing large settlements at the load test. For this reason the pile point tip for common piles was replaced by a rock shoe consisting of rail P43 ($A=50\ cm^2$). However, though pile No.2 and No.3 have rock shoes the safety factor is low. Therefore, in the area of weathered bedrock the small hollow pile was used. The load tests of all small hollow piles give a good result with a safety factor of about two. The hollow pile No.7 was driven without following the stop criteria, had no steel rod. The design load for this type of pile is only 400 kN, due to the limit compressive strength of the cement mortar. The failure of big hollow piles may be due to the connection between the steel rod and the concrete pile, therefore a steel net is used to reinforce (see Fig. 4).

TABLE 3. Summary of test results.

Pile No.	Pile type	Pile length (m)	Rock condition	Design load Q_f (kN)	Load at 6 mm displacement (kN)	Penetration of 3 last series (mm)	Deformation at failure (mm)	Point tip	Failure Q_{ult} (kN)	Safety factor F	Note
1	30x30	13	Hard rock	700	750	3.2.1	11	ϕ4 cm	1000	1.42	Common pile without rock shoe
2	30x30	19	Weathered rock 5% core	700	1000		11	rail P43	1200	1.71	Common pile with rock shoe consisting of 0.5 m of rail
3	30x30	19.9	Weathered rock no sample	700	700	25.20.5	12.5	rail P43	1000	1.43	Common pile with rock shoe consisting of 0.5 m of rail
4	35x35	18.8	Hard rock	700	950	4.2.1	12.5	20x20x x1.5	1900	2.71	Test pile for check of driving criteria. No drilling or injection are performed
5	35x35	16.4	Cavity of 50 cm	700	1200	8.7.3	7.5	ϕ110 mm	1300	1.86	Smaller hollow pile, follow procedure 2.1
6	35x35	17.1	45° inclination cavity of 2 m	700	1600	14.9.6		ϕ110 mm	2500	3.5	Small hollow pile follow procedure 2.1 without showing sign of failure
7	35x35	22.0	Cavity of 6.5 m the roof is 0.5 m	400	-	70.60.50	3.0	20x20x x1.5	850	2.12	Small hollow pile, stop 1.0 m over rock surface, without steel rod
8	ϕ55	15.7	Cavity of 4.5 m	1750	2000	6.5.4	15.4	20x20	3000	1.71	Follow procedure 2.2, without steel net to reinforce connection between concrete pile and steel rod

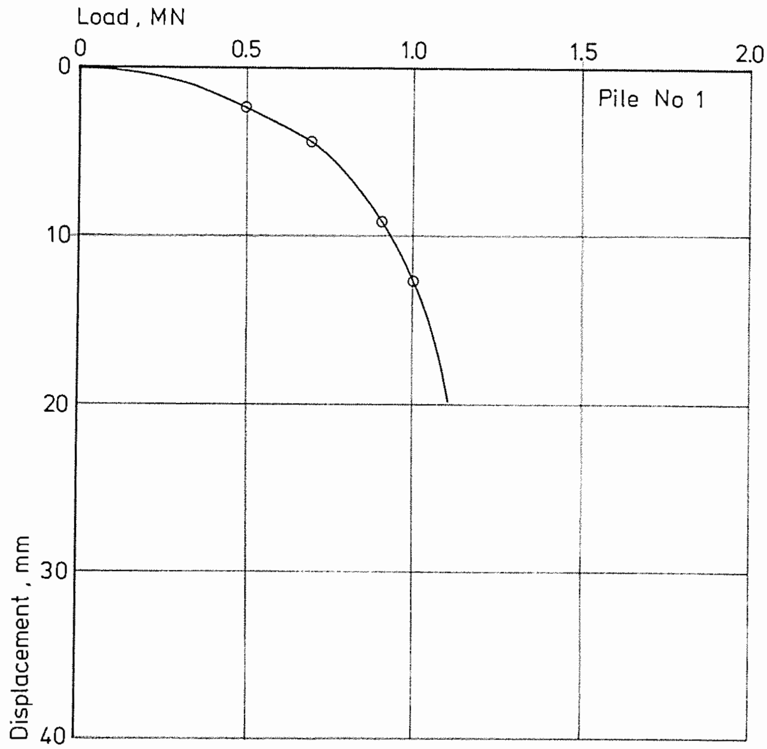

Fig. 5a Load displacement curve for pile 1.

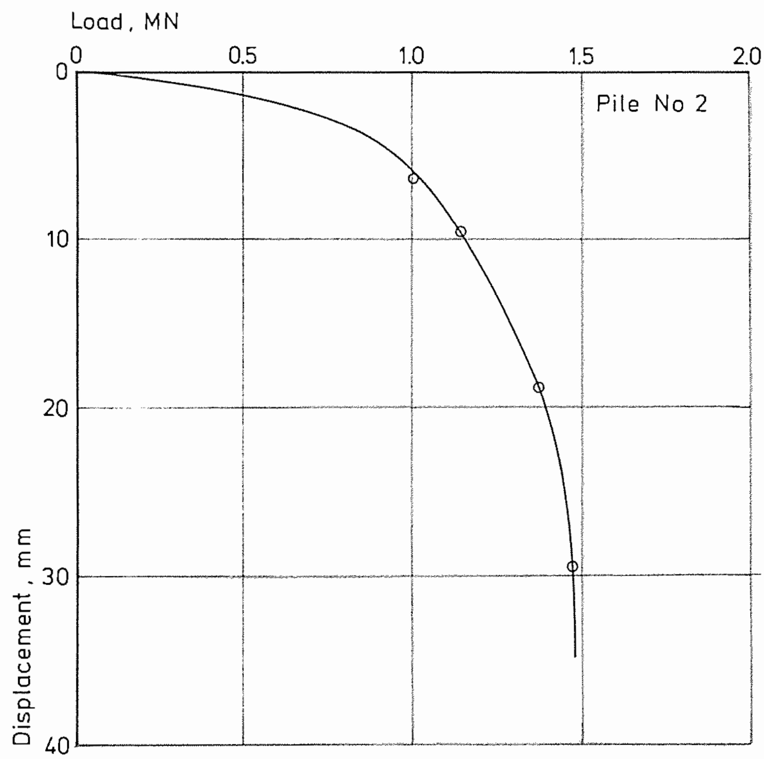

Fig. 5b Load displacement curve for pile 2.

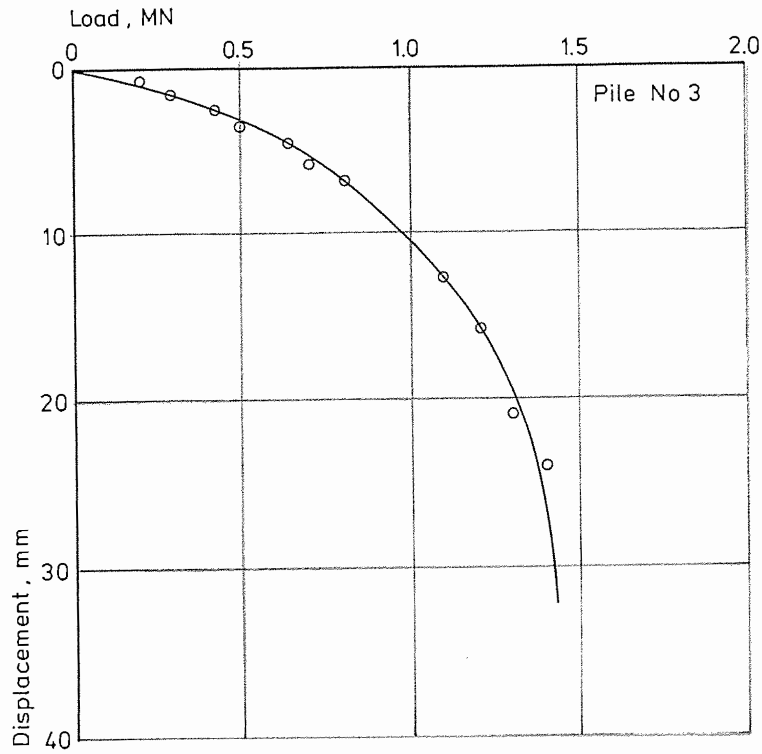

Fig. 5c Load displacement curve for pile 3.

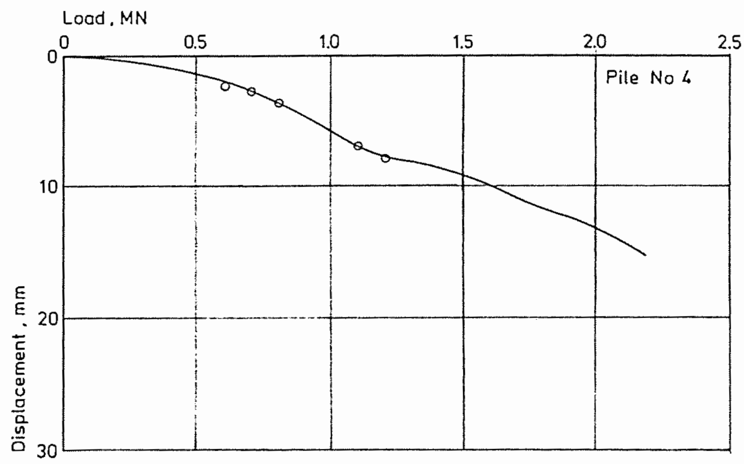

Fig. 5d Load displacement curve for pile 4.

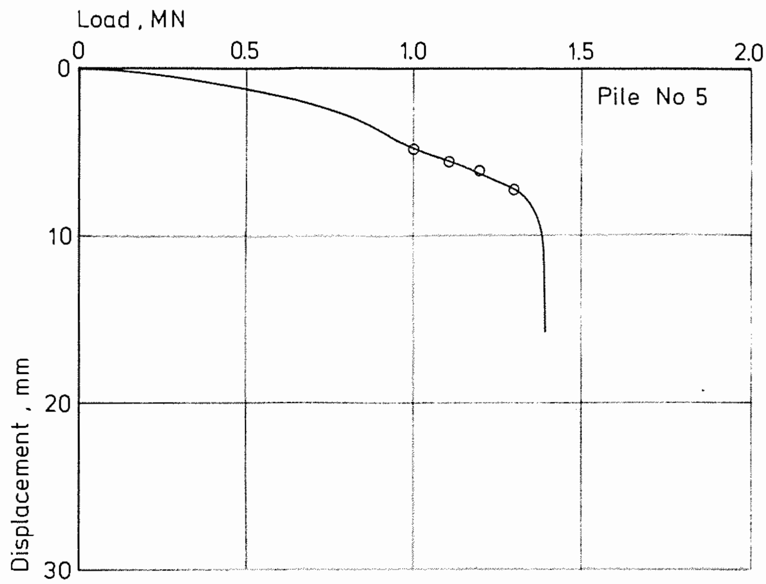

Fig. 5e Load displacement curve for pile 5.

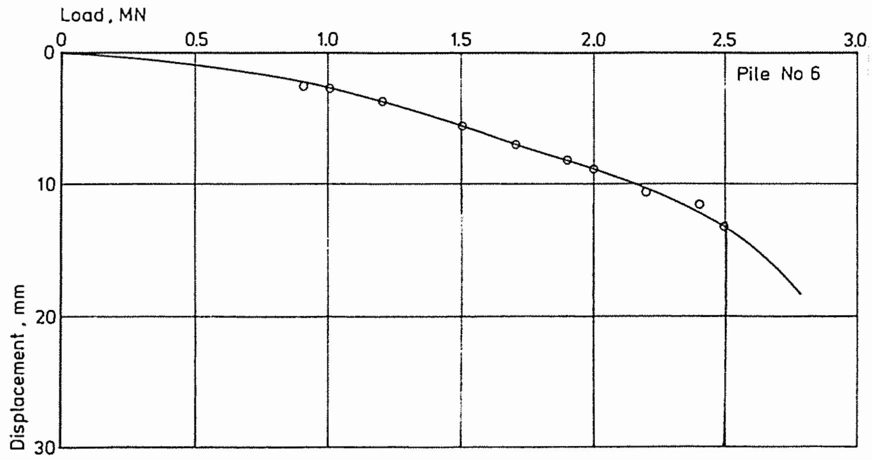

Fig. 5f Load displacement curve for pile 6.

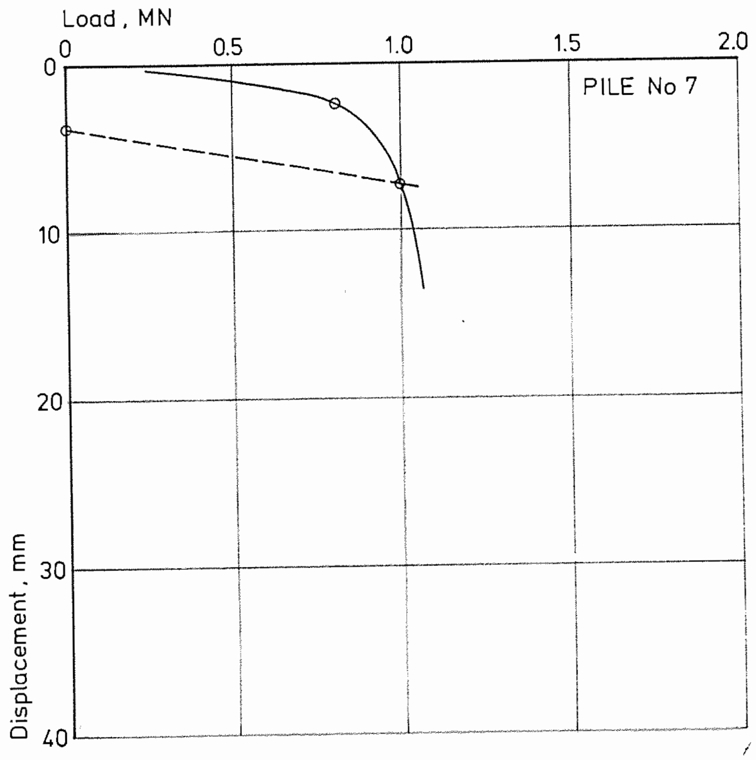

Fig. 5g Load displacement curve for pile 7.

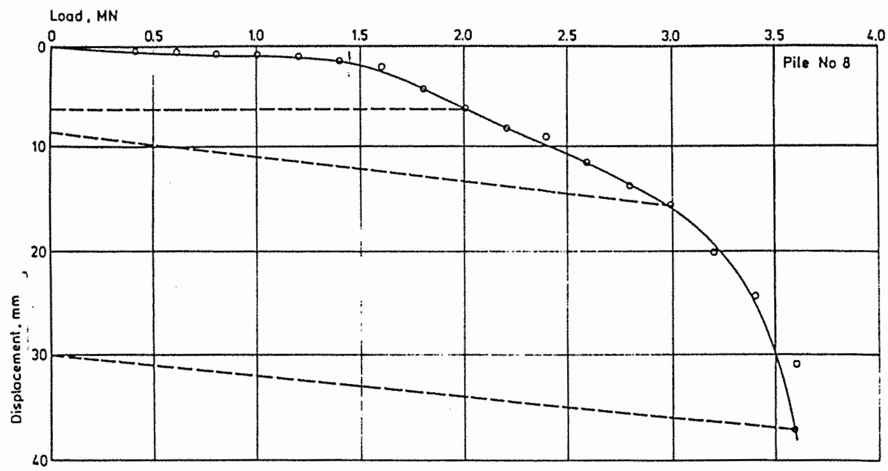

Fig. 5h Load displacement curve for pile 8.

4 Conclusions

4.1 The use of precast concrete hollow piles of different dimensions on carstic limestone is presented. Depending on the design load, dimensions of the cavities the type of the pile is decided. The precast concrete pile is compounded with a steel rod and has successfully been used for the treatment of cavities, steep inclination of the rock surface and weathered rock. By means of the steel rod the load is transferred to deeper sound rock to prevent failure of the pile.

4.2 Grouting at low pressure prevents large losses of grout thus giving high compression strength.

4.3 Piling in carstic limestone can only be economically performed if the designer and the contractor take into account the particularity of the soil investigation, suitable equipment and a good performance of construction.

4.4 The chosen method for the pile foundations presented in this paper is in agreement with the conditions, materials and equipment available in Vietnam. Therefore the foundation work is nearly finished for the cement factory after only 1 year.

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