2nd Int. PhD Symposium in Civil Engineering 1998 Budapest

SOME OBSERVATIONS ON PILED FOOTINGS

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SUMMARY

A piled footing consists of piles linked together by a footing, the footing being in direct contact with the soil. In this paper, a design method for piled footings subjected to vertical loads is briefly described. Observations made on two bridge piers are presented : the first pier was designed with the usual assumption that the piles carry all the applied load ; the second pier was designed taking into account the footing capacity, which allowed for using shorter piles. The settlements and loads measured on the footings are compared with the predicted ones.

Keywords: case history, pile, footing, design method.

1. INTRODUCTION

Many well instrumented buildings have been founded on piled raft in recent years : buildings on stiff clay (Cooke, 1986 ; Yamashita et al., 1993), on soft clay (Jendeby, 1986), on pyroclastic soils (Mandolini et al., 1997), high rise buildings on Frankfurt stiff clay (Franke, 1991 ; Katzenbach, 1997).

Piled footings with various soil conditions have been tested as well : bored piles in sandy silt (Liu, 1989 ; Garg, 1979), driven piles in soft organic soil (Liu, 1994), driven piles in silt (Kondrachov, 1971).

The piles used in piled foundations are termed friction piles, creep piles, settlement reducer piles or standard piles. Theses differences in terms may cover differences in philosophy and method of design. One point of interest is to assess whether the piles should work at low-medium load level, or if the pile capacity should be fully mobilised. In the latter case, non linear behaviour of piles is of first importance.

The main design methods have been reviewed by Randolph et al. (1997) and Van-Impe et al. (1997). A classification in three categories has been proposed by these authors :

1. simplified calculation methods ;
2. approximate computer-based methods ;
3. more rigorous computer-based methods.

A design method of the second type is described hereafter. This method is able to take into account the entire pile load-settlement behaviour.

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2. PROPOSED DESIGN METHOD FOR PILED FOOTINGS

A simple design method was developed based on case histories and specific tests (Combarieu, 1979, 1988). This method is relevant to foundations subjected to a vertical central load. The footing is supposed to be rigid. All the piles are of the same type and an average pile is considered in the analysis, independently of its position in the group.

The general principles of the method are presented below. They can be applied to almost any national design practice, although the French code for foundation design (Fascicule 62 - Titre 5) is mainly based on specific pressuremeter methods within the limit state theory framework.

2.1 The ultimate bearing capacity

For a piled footing with n piles, the ultimate bearing capacity $Q_{u,pf}$ is :

$$Q_{u,pf} = Q_{u,f} + n.m.Q_{u,ps} + n.Q_{u,pp}$$

$Q_{u,f}$: the footing ultimate bearing capacity calculated with a footing area equal to the total footing area reduced by the piles cross section area ;

$Q_{u,ps}$: the average pile ultimate shaft friction taking into account the group effect ;

$Q_{u,pp}$: the average pile ultimate point resistance.

m is a parameter related to the footing influence on pile skin friction. There is no relative pile-soil displacement just beneath the footing and no shaft friction is mobilised in this zone. In practice, μ is determined assuming no shaft friction down to a depth equal to half of the footing width B.

If the pile length L exceeds the footing width B, it is assumed that the pile ultimate point resistance is not affected by the footing.

2.2 The settlement analysis

The settlement analysis is based on separating the load-settlement behaviour for pile group and for single footing.

Load transfer functions are used for evaluating the shaft friction and the point resistance. They are similar to the functions used for piles without footing. At a given depth, the shaft friction is calculated assuming that the relative local soil-pile displacement is reduced by the vertical displacement due to the footing settlement. The vertical settlements can be computed for any pile point settlement value as illustrated in Figure 1. Special rules exist for short piles (L lower than B).

It is assumed that the footing load-settlement behaviour is similar to the behaviour of an isolated footing.

3. FOUNDATION MONITORING FOR A BRIDGE CROSSING THE RN 138

3.1 General description

The presented case history deals with a prestressed concrete bridge built near Rouen which crosses the National Road RN 138 at the highway A 13 exit (Combarieu et al., 1982). This bridge consists of three spans 13.50 m wide and 24.50 m, 28.00 m and 24.50 m long (Fig. 2). The permanent loads on the central piers A3 and A4 are 10.100 MN. The service design load at the Service Limit State (SLS) is 13.920 MN.

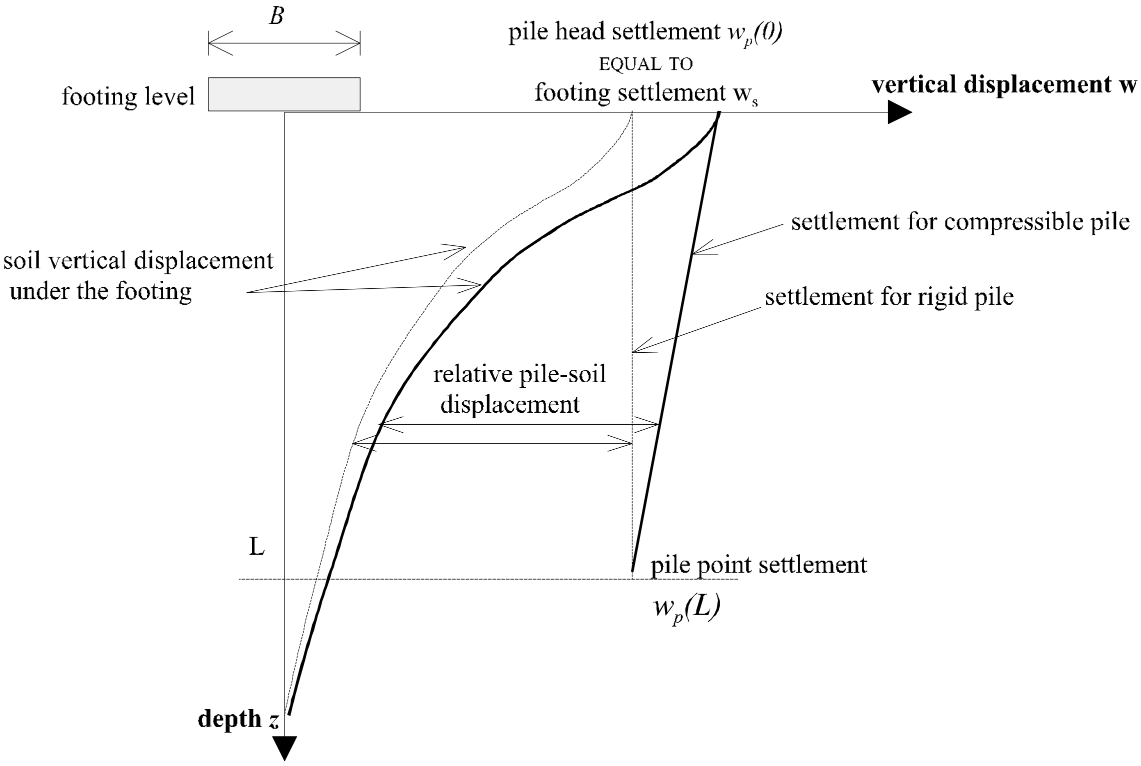


Fig.1 : general procedure for settlement analysis

Up to a depth of 2 meters the soil consists of silt with a pressuremeter limit pressure (PMT) of about p_l=0.500 MPa. Beneath this deposit is a red clay layer containing flints originating from the decalcification of the underlying chalk. The layer is 5 to 10 meters thick with p_l ranging from 0.600 MPa to 2.000 MPa. Below the red clay, chalk has been encountered with p_l>3.000 MPa.

Due to poor soil characteristics near the surface, it was decided to found the bridge on piled foundations. For each central pier 8 bored piles (2x4), 800 mm in diameter, were installed. The concrete footing linking the piles is 8.80 m x 4.00 m x 1.10 m.

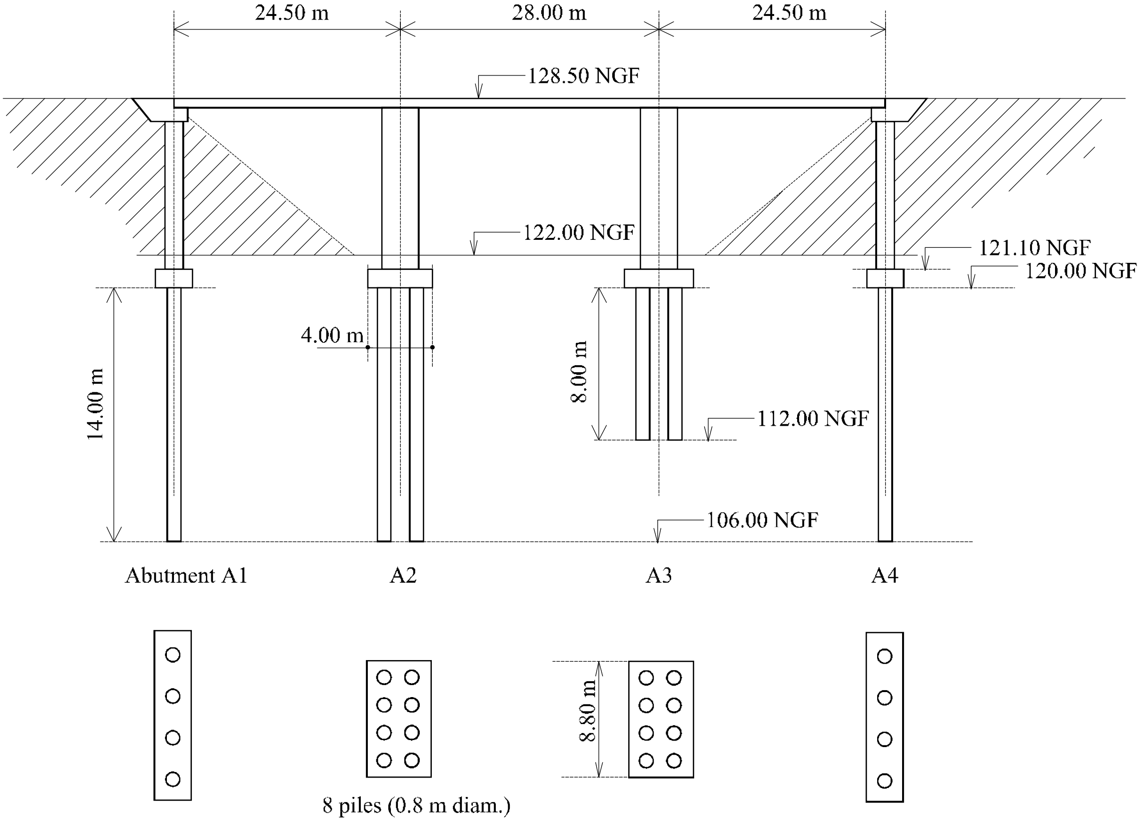
The calculated service loads are presented in Table 1.

Tab 1. : SLS loads for various foundation alternatives

	Service limit load (MN)
Footing alone	8.800
8 piles L=14 m[1]	14.160 to 19.360
8 piles L=8 m	8.400
Piled footing L=8 m	14.530

[1] two cases have been considered depending on the clay/chalk contact depth which is very variable at the foundation location.

It was decided to design the central pier A2 with the usual assumption that the piles carry all the load (pile length L=14 m). The central pier A3 was designed taking into account the load carried by the footing using the method presented above (pile length L=8 m).



NGF : general French elevation reference in meters

Fig. 2 : Schematic view of the bridge

3.2 The settlements

Monitoring the settlements started after concreting the footing and the pier, as presented in Table 2.

Tab. 2 : Foundation settlement

Construction stage achieved	footing + pier	road deck	loading test with trucks
total load	1.550 MN	9.550 MN	11.050 MN
A2 *measured* (L=14 m)	origin : 0 mm	4 mm	4 mm
A2 *calculated* (L=14 m)[1]		1.8 to 2.1 mm	2.2 to 2.5 mm
A3 *measured* (L=8 m)	origin : 0 mm	7 mm	7 mm
A3 *calculated* (L=8 m)		3.8 mm	4.7 mm

[1] two cases have been considered depending on the clay/chalk contact depth which is very variable at the foundation location.

The settlements observed for abutment A3 (L=8 m) are twice the settlements observed for abutment A2 (L=14 m). This ratio is confirmed by the predicted settlements, although the calculated values are equal to 50%-70% of the observed displacements.

3.3 Distribution of the loads between piles and footing

The stresses beneath the footing A3 were monitored using 23 Glötz cells. The observed distribution of stresses and the Glötz cells location are shown on Figure 3. The distribution is quite erratic. No axis of symmetry can be clearly identified. The mean stress under the footing was estimated using an area of influence for each Glötz cell and adding the obtained loads. Table 3 shows the results as well as the calculated loads.

The total load is estimated from the construction plans.

The observed and predicted results show that the footing carries about 20% of the total load applied. Calculated values for abutment A2 (L=14 m) show that the footing would carry 10% of the total load only.

Tab. 3 : Loads on the footing A3 (L=8 m)

construction stage achieved	footing	pier	road deck
total load (MN)	1.000	1.550	9.550
measured footing load (MN)	0.920	0.740	1.600
measured ratio footing/total	92 %	48 %	17 %
calculated footing load (MN)	1.000		2.300
calculated ratio footing/total	100 %		24 %

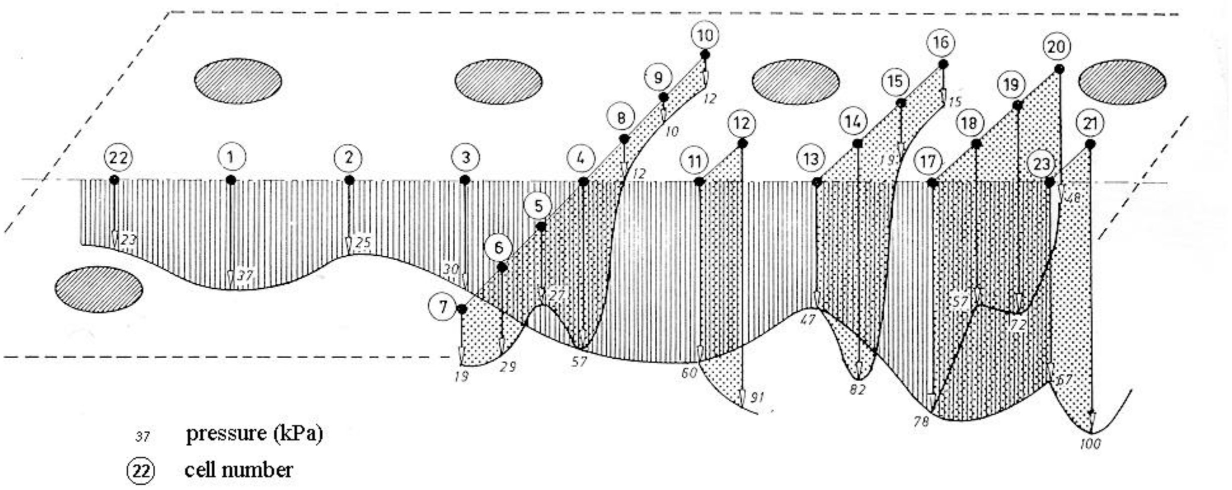


Fig. 3 : Location of Glötz cells and distribution of stresses beneath the footing A3 after construction of the road deck (9.550 MN applied)

The calculated safety factors (defined as the ratio of the ultimate bearing capacity to the applied load) are presented in Table 4. For the observed load (9.550 MN), the pile group is close to its design load for abutment A3 (L=8 m), although only 70% of the design load is applied. With the full design load applied (13.920 MN), the safety factor would reduce to 1.65 for the pile group.

For abutment A2, which was designed without taking the footing capacity into account, the pile group load remains lower than the design load.

Tab. 4 : calculated safety factor

	9.550 MN (applied load)		13.920 MN (design load)	
safety factor	A3 (L=8 m)	A2[1] (L=14 m)	A3 (L=8 m)	A2[1] (L=14 m)
piled footing	4.2	5.5 to 7.1	2.85	3.8 to 4.85
footing	12.	20. to 25.	7.3	13. to 16.5
pile group	2.35	3.6 to 5.3	1.65	2.55 to 3.6

[1] two cases have been considered depending on the clay/chalk contact depth which is very variable at the foundation location.

4. CONCLUSIONS

A simple design method for piled footings is briefly described in this paper. A software allows to use it as an efficient design tool.

According to that method and depending on the soil characteristics, shorter piles can be used when the footing capacity is taken into account.

A case history has been presented consisting of two instrumented bridge piers : the first pier was designed with the usual assumption that the piles carry all the applied load ; the second pier was designed with the proposed method. The settlement as well as the load distribution between the pile group and the footing were monitored.

The observed behaviour agrees with the predicted one. However, it should be mentioned that the soil is quite heterogeneous in the foundation area.

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