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Comparison of different approaches of pile design in chalk adopted in France and UK

Comparaison des différentes approches de la conception des pieux dans la craie adoptées en France et au Royaume-Uni

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ABSTRACT: Chalk is found widespread across northern Europe and under the North Sea, including the continental shelf of France and the UK and is still considered as an important issue for the design of piles. Different methods are used in France and the UK for designing piles in chalk. In France, pressuremeter and penetrometer tests are used for pile designing, in any soil type, according to the French standard for pile design (NF P94-262/A1). CIRIA C574 is the official document for designing piles in chalk in the UK. The aim of this paper is to compare the two practices regarding the pile design under ultimate limit state. For this purpose, a summary of different methods was firstly presented, and then a comparison of different piles calculation results, using data from a French site, was done. The comparison has shown significant differences between results.

RÉSUMÉ: La craie est très répandue à travers l'Europe du Nord et sous la mer du Nord, surtout sur le plateau continental entre la France et le Royaume-Uni. Elle est toujours considérée comme un terrain au comportement complexe pour la conception des pieux. Différentes méthodes sont utilisées en France et au Royaume-Uni pour la conception des pieux dans la craie. En France, les essais pressiométriques et pénétrométriques sont utilisés pour le dimensionnement des pieux, dans n'importe quel type de sol, selon la norme française pour la conception des pieux (NF P94-262/A1). CIRIA C574 est le document officiel pour la conception des pieux dans la craie au Royaume-Uni. L'objectif de cet article est de comparer les deux pratiques concernant la conception de pieux à l'état limite ultime. Dans ce but, un résumé de ces différentes méthodes a été présenté, puis une comparaison des résultats de calcul des différents pieux, en utilisant des données provenant d'un site français, a été effectuée. La comparaison a montré des différences significatives entre les résultats.

Keywords: Chalk; piles; pressuremeter; penetrometer; CIRIA C574

1 INTRODUCTION

Many offshore wind projects are being developed in more complex and challenging ground conditions than sands and clays, as those surrounding the North Sea, and including the continental shelf of the UK, Ireland, France, Denmark and Germany, where the chalk is widely spread (Figure 1).

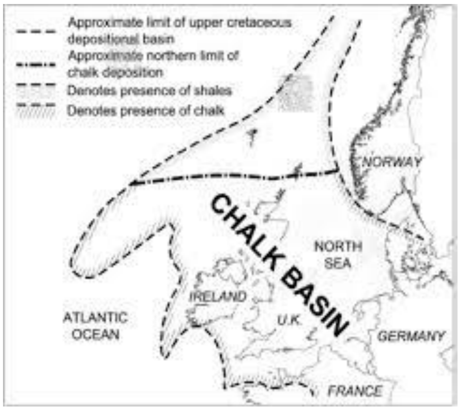

Figure 1.Extent of chalk deposition over the North West European continental shelf (Anderton et al, 1979)

Due to different ground investigation techniques, there are different approaches adopted for the design of deep foundations in chalk. Even if there is a great experience in the design of piles with some well-recognised design guidelines (API, 2011), it appears that there is a little guidance for driven piles design in chalk. In France, at present, the design of piles in chalk is done according to the specifications of the French national standard of the application of the Eurocode 7 for deep foundations NF P 94-262/A1 (AFNOR, 2018). According to this standard, designing of piles is related to in-situ test results, the pressuremeter and the penetrometer. In the UK, the design of piles in chalk, have primarily been done to the recommendations of CIRIA C574 (Lord et al., 2002). This paper aims to compare these two perspectives, giving an overview of the French and British practices. Application to some related case histories is also provided to illustrate this comparison.

2 PILE DESIGN IN CHALK

The bearing capacity of piles can be estimated based on foundation soil parameters determined by previous laboratory or in situ testing. In geotechnical literature, several empirical methods are used for the determination of pile bearing capacity. These methods have been developed from a great number of field tests. In each of these methods, the total pile bearing capacity for the compressive force, R_c, is considered the simple sum of the shaft resistance along the pile, R_s, and the pile base resistance, R_b.

$$R_s = P_s \int_0^L q_s(z)dz \quad (1)$$

Where Ps is the pile perimeter, L is pile length and q_s is the shaft resistance at level z.

$$R_b = A_b * q_b \quad (2)$$

Where A_b is the pile base area and q_b is the unit resistance on the base.

Therefore, the difference between these several methods is the determination of R_s and R_b.

2.1 French perspective

Some methods are based on the knowledge of the intrinsic mechanical properties of soil, c and φ (Caquot & Kerisel, 1966). But for chalk, these methods can't be used. The chalk of the Paris Basin, which is almost always more or less altered to great depths, cannot be collected in intact form (Pasturel, 1968). For this reason, pressuremeter and penetrometer tests are the most used.

The Fasicule 62 Title V (MELT, 1993) has been adopted since 1993 by the Ministry of Equipment. It groups rules for calculating pile capacity from pressuremeter and penetrometer tests. However, many tests of static pile loading have been carried out since 1990 and have not been taken into account in the development of

Fasicule 62-V rules (MELT, 1993). Bustamante and Gianeselli (2006) used these pile tests and older tests, available in the LCPC database, to propose new rules for calculating pile resistance. More recently, the old calculation rules as well as those presented by Bustamante and Gianeseli (2006) have been revised by Burlon et al. (2014). The objective of this revision is the need to implement of the Eurocode 7 into French practice, which led to the publication of the new French standard for the application of Eurocode 7 to deep foundations NF P 94-262 (AFNOR, 2012).

2.1.1 Pressuremeter method (PMT)

The design of piles according to the pressuremeter results consists in correlating the base resistance and the shaft resistance to the limit pressure.

The value of the shaft resistance is calculated according to the following general expression:

$$q_s(z) = \alpha_{pile-soil} * f_{soil}(p_l^*) \quad (3)$$

Where p_l^* is the net limit pressure (PMT), $\alpha_{pile-soil}$ is a dimensionless parameter depending on soil and pile type (Table 1) and f_{soil} is a function depending on type of soil and limit pressure p_l^*.

$$f_{soil}(p_l^*) = (a * p_l^* + b) * \left(1 - e^{-cp_l^*}\right) \quad (4)$$

Where a, b and c are soil dependant parameters. For chalk, $a=0.007$, $b=0.07$ and $c=1.3$.

The value of the base resistance is calculated according to the following general expression:

$$q_b = k_p * p_{le}^* \quad (5)$$

Where p_{le}^* is the equivalent net limit pressure and k_p is the pressuremeter bearing capacity factor. k_p is a function of soil type and pile class (Table 2).

$$p_{le}^* = \frac{1}{3a+b}\int_{L-b}^{L+3a} p_l^*(z)dz \quad (6)$$

With $a=max\{\frac{B}{2};0{,}5\}$ and $b=min\{a;h\}$

Where L is the pile length, B is the pile diameter and h is the height of the pile contained in the bearing layer.

2.1.2 Penetrometer method (CPT)

The value of the unit shaft resistance at the depth z is determined from the following relation:

$$q_s(z) = \alpha_{pile-soil} * f_{soil}[q_c(z)] \quad (7)$$

Where q_c is the cone resistance, $\alpha_{pile-soil}$ is a dimensionless parameter depending on soil and pile type (Table 1) and f_{soil} is a function depending on type of soil and q_c values.

$$f_{soil}(q_c) = (a * q_c + b) * (1 - e^{-cq_c}) \quad (8)$$

Where a, b and c are soil dependant parameters. For chalk, $a=0.0015$, $b=0.1$ and $c=0.25$.

The value of the base resistance is calculated according to the following general expression:

$$q_b = k_c * q_{ce} \quad (9)$$

Where q_{ce} is the equivalent penetration resistance and k_c is the penetrometer bearing capacity factor. k_c is a function of soil type and pile class (Table 2).

2.2 British perspective

Until recently, designing of piles in chalk have been done according to the recommendations of CIRIA PG6 (Hobbs & Healy, 1979). It includes a series of empirical relationships, based on several case histories then available, between the SPT blowcounts and shaft and base resistances for different pile types.

Table 1.Values of $\alpha_{pile\text{-}soil}$

Pile class	Pile category	$\alpha_{pile\text{-}soil}$ (PMT)	$\alpha_{pile\text{-}soil}$ (CPT)
C1: Bored piles	1. No support	1.8	0.80
	2. With slurry	1.8	0.80
	3. Permanent casing	0.5	0.25
	4. Recoverable casing	1.7	0.75
	5. Dry Bored Pile/ or Slurry Bored Pile with Grooved Sockets	-	-
C2: CFA piles	6. CFA pile	2.1	0.95
C3: Screw piles	7. Screw cast in place pile	1.7	0.75
	8. Screw piles with casing	1	0.45
C4: Closed-ended driven piles	9. Pre-cast or Pre-stressed Concrete Driven Pile	1	0.45
	10. Coated Driven Steel Pile (coating concrete, mortar, grout)	1.9	0.85
	11. Driven cast-in-place pile	2.1	0.95
	12. Driven steel pile, closed-ended	0.4	0.20
C5: Open-ended driven piles	13. Driven steel pile, open-ended	0.5	0.25
C6: Driven H piles	14. Driven H pile	0.4	0.20
	15. Driven grouted H pile	2.4	1.10
C7: Driven sheet pile walls	16. Driven sheet pile	0.4	0.20
C8: Micropiles	17. Micropile I (gravity pressure)	-	-
	18. Micropile II (low pressure)	-	-
	19. Micropile III (high pressure)	2.4	1.10
	20. Micropile IV (high pressure with TAM)	3.1	1.40

Table 2.Bearing resistance factors

Pile class	C1	C2	C3	C4	C5	C6	C7	C8
k_{pmax}	1.45	1.6	2.35	2.3	1.4	1.7	1	1.45
K_{cmax}	0.3	0.3	0.4	0.4	0.15	0.35	0.15	0.3

Nowadays, CIRIA C574 is considered the official guide for pile dimensionning in chalk.

2.2.1 Shaft resistance

- *Bored piles*: After more case histories were available, by increasing the range of piles considered, improving the understanding of chalk behaviour and reviewing available plate loading and pile load test, Lord (1990) concluded the need for a different design approach.

CIRIA C574 recommends that, whilst the end bearing capacity should continue to be calculated on the basis of SPT results, the shaft capacity should be calculated on the basis of the average vertical effective stress along the shaft, as followings:

$$\tau_{sf} = k * tan\delta' * \overline{\sigma_v'} = \beta * \overline{\sigma_v'} \quad (10)$$

Where k is the coefficient of earth pressure, δ' is the effective angle of interface friction, and $\overline{\sigma_v'}$ the average verticale effective stress.

CIRIA C574 assigns β value of 0.8 to bored piles in low and medium-density chalk.

For high-density chalk, the pile should be treated as rock socket and the shaft capacity is es--timated as:

$$\tau_{sf} = 0.1\, q_c \quad (11)$$

Where q_c is the uniaxial crushing strength of the chalk.

- *CFA piles (Continuous Flight Auger):* Using the vertical effective stress procedure proposed for bored piles, a prudent design line for CFA piles in chalk would be:

$$\tau_{sf} = 0.45\, \overline{\sigma_v'} \quad (12)$$

This value is a lower bound to a very limited number of selected test results.

- *Driven cast in place piles:* Using the vertical effective stress procedure, and considering that the normal stress to which the remoulded chalk around the pile shaft had been subjected is expected to be similar to that for bored piles, the β value of this type of piles would be equal to 0.8.

- *Driven pre-formed piles:* In this category there are two types of piles, small displacements piles such as H-piles, open-ended steel and box piles, and large displacement piles such as precast concrete piles, closed-ended steel tubes and boxes.

The limiting shaft resitances recommended by CIRIA C574 ranges from 10 to 20 kPa in small displacement piles in low to medium-density chalk, and up to 120 kPa in high density grade A chalk. As for large displacement piles, these limits range from 30 to 50 kPa.

2.2.2 *Base resistance*

The determination of pile base resistance in chalk is related to the, no corrected, *SPT N* values. It is recommended that the following ultimate base stresses be adopted for:

- bored piles:

$$q_u = 200 * N \text{ kPa} \quad (13)$$

- CFA piles:

$$q_u = 200 * N \text{ kPa} \quad (14)$$

- driven cast-in-place piles:

$$q_u = 250 * N \text{ kPa} \quad (15)$$

- driven preformed piles:

$$q_u = 300 * N \text{ kPa} \quad (16)$$

3 CASE STUDY

In order to compare pile compressive resistance according to French and UK standards, a number of examples will be introduced.The considered site is located in Fleury-sur-Andelle which is a French commune located in the Eure department in the Normandy region. Figure 2 illustrates the geotechnical profile as well as results from PMT, CPT and SPT. These tests were executed within the LCPC laboratory in the 1979.

First, the comparison will be held between results from different approaches as well as results from pile load tests. Two types of piles, square precast concrete and closed ended steel cylindrical pile, are considered. Second, three types of cylindrical piles, CFA, precast concrete and open ended steel piles, are considered just for the comparison between different approaches.

Table 3 lists the geometry parameters of each pile, and Table 4 presents the parameters needed for the calculation according the British approach. Due to the lack of SPT N values below 10 m of soil depth, the corresponding value at 10.2 m was estimated by extrapolating the trendline between 9 and 10 m.

Results of calculation are presented in Table 5. Overall, there are very large discrepencies between results. The French approaches give much better estimation of the total bearing capacity compared to static pile results.The pile base resistances estimated according to CIRIA is greater than those estimated by French standards, and also much greater than the correspondent pile shaft resistances.

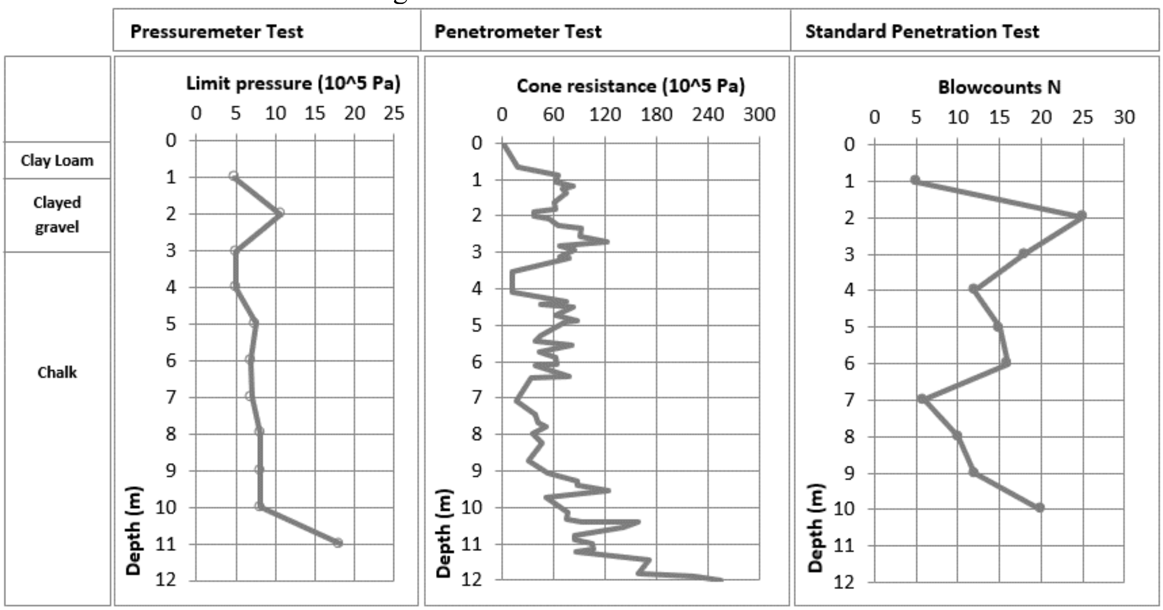

Figure 2. In situ test, Fleury-sur-Andelle (Bustamante et al., 1979)

Table 3.Piles geometry parameters

Pile		**Section dimensions (cm)**	**Length (m)**
In-situ	Square precast concrete	40	10.2
	Closed ended steel	44.5	10.2
Example	CFA	50	10
	Precast concrete	40	10
	Open ended steel	50	10

Table 4.British calculation parameters

Soil description	**Soil property**	**Calculation parameters**			
		Square precast concrete	**Closed ended steel**	**CFA**	**Open ended steel**
Clay loam	φ'=20° $\overline{\sigma'_v}$=8.5 kPa	β=0.3	β=0.3	β=0.3	β=0.3
Gravel	φ'=35° $\overline{\sigma'_v}$=19.5 kPa	tanδ=tan(0.67φ')=0.45 k_s=1	tanδ=tanφ'=0.7 k_s=1	tanδ=tanφ'=0.7 k_s=1	tanδ=tan(0.67φ')=0.45 k_s=0.8
Chalk	$\overline{\sigma'_v}$=62.2 kPa	q_s=30kPa	q_s=30kPa	β=0.45	q_s=20kPa
Chalk: base 10 m	N=20bl	q_b=300N	q_b=300N	q_b=200N	q_b=300N
10.2 m	N=22bl				

Figure 3 illustrates unit shaft resistance profile of each example pile determined according to different method of calculation.

In general, the pressuremeter method gives the highest values regardless of the pile type. The difference between results is the highest for the CFA pile, where the database for this pile technique is considered limited in the British practice compared to the French one. For the precast concrete piles, the difference is smaller but it is always in the advantage of the French methods especially the pressuremeter method.

Table 5.Calculation results

Pile	French Standard						UK standard			Static test
	PMT			CPT			CIRIA			
	R_s (kN)	**R_b (kN)**	**R_c (kN)**	**R_s (kN)**	**R_b (kN)**	**R_c (kN)**	**R_s (kN)**	**R_b (kN)**	**R_c (kN)**	**R_c (kN)**
Precast concrete	761.4	552.9	1314.3	630.8	552	1182.8	369.2	1056	1425.2	1090
Closed ended steel	356.2	327.1	683.3	345.8	201.1	546.9	343.1	1026.5	1369.9	700
CFA	1349.2	426	1775.2	1029.5	500.7	1530.2	360.2	785.4	1145.6	-
Precast concrete	583.8	392	975.8	482	427.2	909.2	290	754	1044	-
Open ended steel	377	372.7	749.7	325.7	250.3	576	256.4	1178.1	1434.5	-

For the open-ended cylindrical piles, we almost have the same trend.

CIRIA approach seems to be conservative in comparison to the French standards. This is because the British practice made the shaft resistance depends on the vertical effective stress which is considered small for the chalk.

4 CONCLUSION

This paper aimed to summarise key aspects of the present rules adopted in France and UK for designing pile foundations in chalk. Different approaches are adopted for piles designing in chalk due to different ground investigations techniques used in each country.

Based on some field data from a french site, It was observed that CIRIA approach is too conservative regarding the shaft resistances, and gives high values of base resistances. Somehow, French approaches seem to give better estimation of pile resistance compared to static pile resistance. This can be due, perhaps, to the origin of selected study site, French site. After all, designing a pile in different standards is nothing but a work of estimation depending on results from pile load tests in the corresponding country.

Further comparative researches, relative to results from pile load tests, should be conducted to compare both approaches more in details.

5 ADKNOWLEDGEMENT

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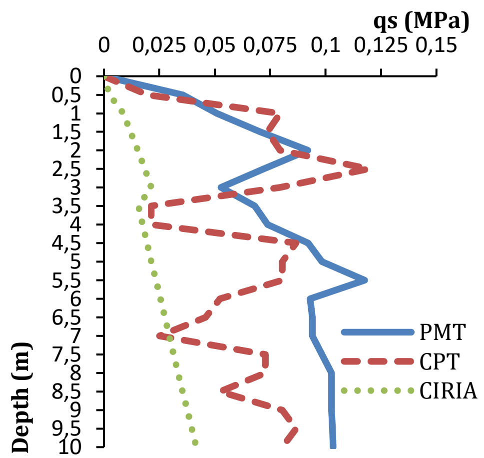
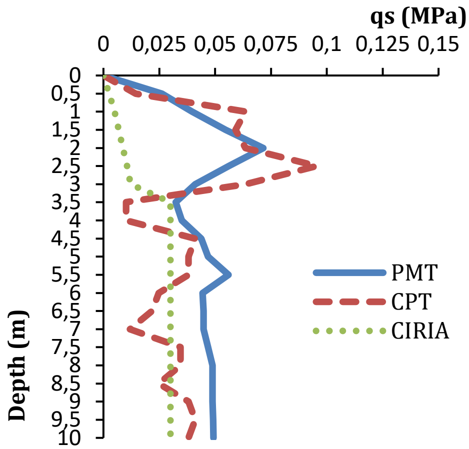
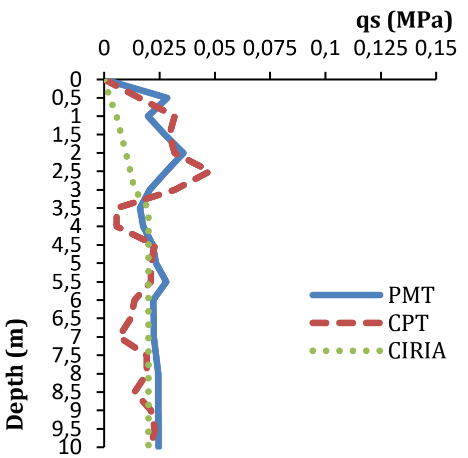


a. CFA Pile



b. Precast concrete pile



c. Open ended cylindrical steel pile

Figure 3. Shaft resistance profiles

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