Federation of Piling Specialists

The design of bored piles in chalk

The introduction of CIRIA Report PR11[i] in January 1994 was intended to 'extend and advance' the earlier report, PG6[ii], by increasing the range of foundations considered, improving the understanding of the behaviour of chalk and reviewing available plate loading and pile load test data. In regard to bored pile design PR11 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, using the following equation:

Average shaft friction τ_{sf} = $K \times \tan \delta' \times \sigma_v'$
= $\beta \times \sigma_v'$

<u>where</u> K = coefficient of earth pressure (σ_h'/σ_v')
σ_v' = average vertical effective stress
δ' = effective angle of interface friction

The report notes that this concept is open to some debate in jointed weak rock, and that there are insufficient data to confirm the relationship. Nevertheless the report concludes that a relationship does exist and assigns β values of 0.8 to conventional bored piles and 0.45 to CFA piles. The latter value is a lower bound to a very limited number of selected test results.

The earlier report, PG6, has been found to give generally conservative designs for bored piles. This was emphasised by the high proportion of load test results that indicated that the tested pile had not been displaced enough to yield reliable estimates of the actual base and shaft capacities. Following publication of PR11 it rapidly became apparent that the new approach was yielding more conservative designs, particularly for CFA piles and particularly in medium and high density chalk.

After collaboration between CIRIA and the FPS a further report, PR86[iii], was published in 2003. On the basis of further test results PR86 addresses the issue of shaft friction on CFA piles in chalk. The report summary recommends that "unless it can be demonstrated that medium density chalk is present over all the pile shaft, the effective stress pile friction coefficient β should be taken as 0.45 throughout". Where medium density chalk (demonstrated by $N > 10$ or $q_{uc} > 4$ MN/m^2) is present over the whole shaft, the report allows that β may be taken as 0.8. This cautious approach appears to reflect continuing uncertainty over shaft friction in chalk.

PR86 represents an advance in the design of piles in chalk but does not fully address discrepancies between the perceived behaviour of bored piles in chalk and the design method recommended in PR11. Further discrepancies between the results of design to PG6 and PR11 appear to arise mainly from the switch to an effective stress based method and are equally applicable to CFA and conventional rotary piles.

Figures 1 and 2 present predicted pile lengths in chalk, using PR11/PR86, for a variety of differing conditions, using a 'low' SPT profile (N = 5 + z) and a 'high' SPT profile (N = 20 +z) respectively. Each figure presents three conditions:

a) 2m natural overburden over chalk
b) 7m natural overburden over chalk
c) 7m recent fill over chalk

The corresponding results of PG6 (based only on the results of conventional rotary piling) are added for comparison. In all cases 600mm diameter CFA piling has been assumed, and the groundwater table has been taken to be at 7m depth. In the case of 7m of recent fill overlying chalk, the PR11/PR86 analyses have allowed for the recommendation that increases in vertical effective stress due to placement of fill should be ignored.

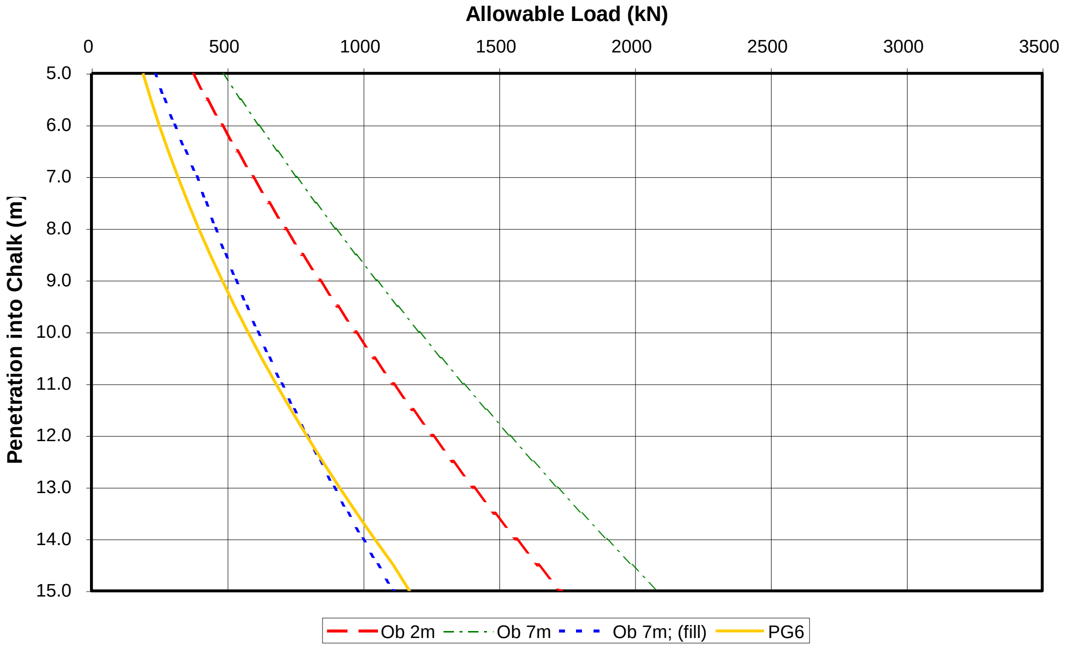

Figure 1 ***Low SPT profile***: *allowable bearing capacities for varying overburden conditions*

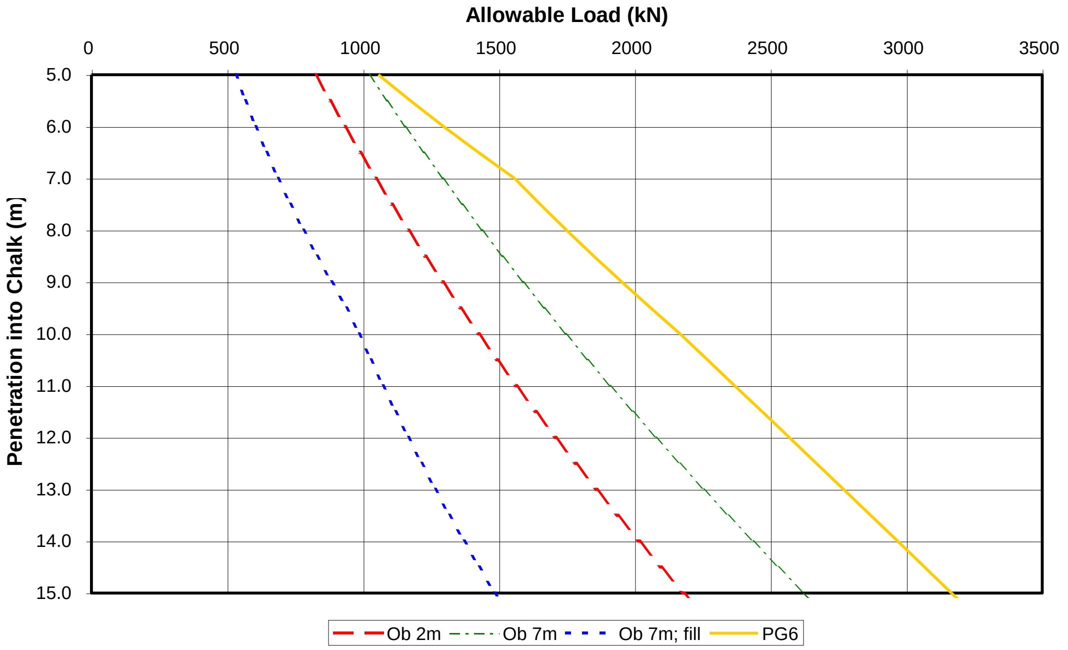

Figure 2 ***High SPT profile***: *allowable bearing capacities for varying overburden conditions*

Figures 1 and 2 demonstrate the influence of effective stress level on predicted pile capacities using the PR11/PR86 approach. For both low and high SPT profile cases the imposition of an extra 5m of natural overburden increases the capacity by typically 20-25%. In contrast, ignoring the effect of recently placed fill causes a significant reduction in estimated capacity. In the case of 7m of fill this requirement of PR11 adds some 5m to 6m to the pile length and represents a significant financial impact on piling costs.

The wide range of results given in the two figures reveal that any agreement, or otherwise, between PR11 and PG6 is merely a function of the particular effective stress condition in the chalk, and carries little significance except in the light of the perceived safety of designs to PG6. In the case of low SPTs (Figure 1) the higher estimates of pile capacity with PR11 are consistent with the findings of authors such as Twine & Grose[iv] which suggest that PG6 underestimates pile capacities in poor quality chalk. However the significantly lower capacities given by PR11/PR86 for a high SPT profile (adding some 8m to pile length) are not apparently consistent with the results of many years of practice using PG6 and represent a significant increase in piling costs to clients.

Report PR11 presently recommends that unless proven otherwise by pile test, the thickness of overlying made ground and fill should be neglected in calculating the vertical effective stress (σ_v'). In contrast the report also recommends that, where overburden is to be removed, σ_v' should be calculated from the reduced ground level. These cautious statements are contradictory in dealing with stress changes and reflect uncertainty in applying an effective stress based method to a weak rock such as chalk.

The supposition that shaft capacity in chalk is directly proportional to the vertical effective stress is based on the simple premise that both parameters increase with depth. However shaft friction could be expected to be directly related to the horizontal effective stress (σ_h'). Since β (=k.tanδ) is held to be constant, the theory put forward in PR11 implies that the horizontal effective stress (σ_h') is directly proportional to σ_v'. In chalk this is questionable.

The results plotted in Fig. 2.2 of PR86 do not, as suggested, demonstrate that shaft friction varies proportionally with vertical effective stress. In fact the figure strongly suggests that shaft friction is largely independent of vertical effective stress. This independence probably reflects the relative independence of σ_h' to σ_v' in weak rock. Indeed PR11 notes that "evidence from two sites indicates that short term increases in σ_v', such as induced by made ground and filling, do not change σ_h". An exception might be anticipated in very weak chalk, although the results plotted in Fig. 2.8 of PR86 appear to refute this.

Conclusion

The publication of CIRIA Report PR86 represents a step forward in improving the design of CFA piles in chalk. However the general design of all bored piles in chalk is still clouded in uncertainty. Neither the SPT based approach of CIRIA Report PG6, nor the effective stress based approach of PR11, produce consistently accurate estimates of bearing capacity, although the better understanding of the behaviour of chalk given in PR11/PR86 allows greater confidence to be taken in producing economic designs with either method.

The FPS continues to encourage its members, consulting engineers, and clients to specify and report more extensive and detailed testing of piles in chalk so that a more satisfactory understanding of pile design in chalk can be obtained. Appendix 3 of CIRIA Report PR86 gives useful guidance on the minimum necessary data requirements. In designing a load test in chalk to reach failure it should be borne in mind that bored piles in chalk commonly perform significantly better than predicted. Given the uncertainties surrounding the use of the SPT in chalk, comparison with other investigative methods such as the static cone penetrometer would also be helpful.

At the present time the following approach to design is suggested:

Poor quality chalk ($N < 10$; $q_{uc} < 4$ MN/m^2)

Compare the results of PG6 and PR11/PR86. Use the more conservative answer without load testing, or combine preliminary load testing with the more optimistic result.

Better quality chalk ($N > 10$; $q_{uc} > 4$ MN/m^2)

Use PR11 without load testing, or combine the results of PG6 with pile load tests. An exception may arise where piles reach chalk at a significant depth. Owing to the high vertical effective stress the chalk penetration suggested by PR11 may be short and should again be compared with the result of PG6 and/or confirmed with pile load testing.

Grade A chalk :

Design as a rock socket in accordance with PR11.

References

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[i] Lord, J. A. et al (1994); *Foundations in chalk* ; CIRIA Project Report PR11

[ii] Hobbs, N. B. & Healy, P.R. (1979) ; *Piling in chalk* ; CIRIA Report PG6

[iii] Lord, J. A. et al (2003);*Shaft friction of CFA piles in chalk*; CIRIA Project Report PR86

[iv] Twine, D. and Grose, W. (1990); Discussion Session III; Proc. Int. Chalk Symp.; Brighton, 1989; Thomas Telford; London, pp 417-419

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