SOME REMARKS ON THE APPLICATION OF THE CECP2 AND BS8002 METHODS FOR THE ANALYSIS AND DESIGN OF ANCHORED SHEET PILE WALLS

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ABSTRACT
The main aim of the present study was to assess the suitability and consistency of the CECP2 and BS8002 codes when used for the analysis and design of anchored sheet pile walls in both cohesive and cohesionless soils. It was found that in the case of cohesionless soils the conventional procedures based on the CECP2 code yielded similar embedment depths although factors of safety as well as forces in the anchor rod differ markedly. In contrast the limit state design approach of BS8002 gave a slightly greater embedment depth but lower factor of safety. Its results suggest that in practice there is an optimum embedment depth in regard to cohesionless soils. With reference to cohesive soils the conventional procedures based on CECP2 gave greatly differing embedment depths depending on whether the factor of safety is applied to the computed depth or to the cohesion term. In addition the factors of safety obtained differed significantly. The BS8002 limit state approach assuming the worst credible loading gave embedment depth approximately intermediate between the values obtained using the conventional procedures of CECP2. For both cohesionless and cohesive soils the BS8002 approach appears consistent because greater embedment depths generally lead to higher factors of safety, but a corresponding decrease in the anchor rod forces.

Keywords: *Anchored, pile, cohesive, cohesionless, embedment, depth, factor, safety*.

1. INTRODUCTION

Retaining walls have found increasing use in construction in recent decades due to the greatly increased need for urban, economic and social development all over the world. Anchored sheet pile walls or, more succinctly, anchored bulkheads serve the same function as retaining walls but, unlike the latter whose weight is a considerable fraction of the weight of the sliding wedge, bulkheads generally comprise a single row of comparatively light sheet piles driven to earth at the lower ends but with the upper ends anchored by tie rods. The tie rods are held securely by anchors buried in the backfill some distance from the sheet pile. The use of anchor rods will generally reduce the depth of penetration, lateral deflection and the bending moments in the pile [1].

On account of the ever increasing demand for these structures several notable developments in the analysis and design of anchored and cantilever sheet piles have taken place in recent decades [2–12]. An overview of the more significant developments is provided by Craig [13] and no further detailed comments are deemed necessary here. One of the more popular conventional methods which have been applied in a number of variant forms is that represented by the CECP2 code [3]. Although the method has often provided satisfactory solutions in several cases it has been found not to be totally accurate and to possess some shortcomings [6]. An alternative and relatively more recent approach contained in the BS8002 code [14] is based on limit state design philosophy and represents a radical shift from the conventional method of CECP2. However this dichotomy has generated a lot of controversy in the geotechnical community in respect of the analysis and design of earth retaining structures.

It is as a consequence of the above that the present study was embarked upon. The main objective was to compare and contrast the results of analysis and design of anchored sheet pile walls using the CECP2 and BS8002 methods. An earlier study [15] was devoted entirely to cantilever sheet piles. Case studies and investigations of existing walls have not been attempted here and for the present study the approach employed has been mainly theoretical. The values of soil design parameters utilized were generally assumed although such values could be described as good representations of those obtained in local practice.

2. METHODOLOGY

There are two classical methods currently in use for the design of anchored sheet pile walls, the free- earth and the fixed-earth approach. However the latter is adopted in the present study on account of its greater simplicity. It is assumed that the sheet pile is rigid and will rotate about the anchor rod level. Passive pressure develops in front of the pile while active pressure develops behind the embedded wall. Failure occurs by rotation about the fixed anchor rod. In relation to the conventional CECP2 method and its variants, once the embedment depth is calculated its value is increased by approximately 20% to 40%, or alternatively, a reduction factor of 1.5 is applied to K_p (the coefficient of passive earth pressure) for cohesionless soils and to c (the cohesion term) for cohesive soils. Only stability conditions have been considered in the present study.

2.1 Anchored Sheet Piles in Cohesionless Soils

The pressure distribution diagram based on the conventional method in the absence of water in the backfill is shown in Figure 1. Following Bowles [16] the depth of penetration X of the sheet pile below the point of zero pressure is given by

$$2X^3 + 3X^2(h_3 + a) - \frac{6R_a\bar{y}}{G_k} = 0 \qquad (1)$$

The force in the anchor rod P_{ar} is given by the following expression:

$$P_{ar} = R_a - R_p \qquad (2)$$

When the anchored sheet piles are to be designed according to the BS8002 code [14] the pressure distribution diagram shown in Figure 2 is used. Stability of the wall is based on equilibrium, that is, the restoring moment should equal the disturbing moment. Also the mobilized soil strength, ϕ_{mob} is utilized and a surcharge of $10KN/m^2$ on the retained soil is applied. Furthermore a compulsory 0.5 m over-dig level or 10% of the total height retained is assumed, in order to provide for unforeseen and accidental events. From Figure 2, moment equilibrium is got by taking moments about the anchor rod level, yielding

$$R_a\bar{y} - R_p y' = 0 \qquad (3)$$

where $y' = 0.67D + h$, and D is the depth of embedment. For horizontal equilibrium an identical relationship to equation (2) is used.

2.2 Anchored Sheet Piles in Cohesive Soils

The analysis is based on the free-earth method using the conventional CECP2 methodology and using the BS8002 design procedure. For the current purpose it has been assumed that the backfill material is cohesionless and the sheet pile wall is only embedded in cohesive material. The pressure distribution diagram based on the conventional method for the anchored sheet pile in cohesive, or $\phi = 0$, material is shown in Figure 3. Following Bowles [16] the embedment depth D is obtained from the expression

$$D^2 + 2Dh_3 - \frac{2\bar{y}R_a}{4c - \bar{q}} = 0 \qquad (4)$$

Using the BS8002 design procedure the compulsory 10 KN/m^2 surcharge is applied to the backfill up to the level of the dredge line. Also a fraction of the peak soil strength is used in the earth pressure calculations. In addition the unplanned excavation of not less than 0.5m or 10% of the retained height is incorporated.

3. RESULTS AND DISCUSSION

Results obtained for the analysis and design of anchored sheet piles in both cohesionless and cohesive soils are presented in Tables1 and 2 respectively. Every attempt has been made to ensure uniformity of design parameters in respect of the CECP2 and BS8002 methods in order to aid the comparative study.

From Table 1 in relation to cohesionless soils, it is obvious that the embedment depths obtained using the conventional methods based on CECP2 and its variants are very similar although the factors of safety (F.S.) are very different. A 30% increase in the calculated embedment depth results in an F.S. of 2.04 as compared to an F.S. of 1.53 when a reduction factor is applied to the coefficient of passive resistance, K_p. In contrast the BS8002 design method gives a relatively slight increase in embedment depth. If the BS8002 method is adopted with an F.S. greater than unity, this gives rise to a greater embedment depth and a smaller force in the anchor rod. An increase in the embedment depth will result in an increase in the factor of safety and a decrease in the anchor rod force. However calculations not shown here suggest that for the present study, for an embedment depth in Table 1slightly in excess of 3.7m, the passive forces become greater than the active forces leading to negative values of anchor rod forces. This is impractical however and would suggest that the anchored sheet pile has an optimum embedment depth beyond which any further increase in depth becomes unreasonable. In Figure 4 the relationship between the factor of safety and the embedment depth based on the BS8002 method is presented. It is obvious that in the sheet pile under consideration, for embedment depths D below 3.5m, the variation between F.S. and D is reasonably linear. Beyond this point however relatively much larger increases in F.S. occur. As noted earlier for the present design study, an embedment depth D of 3.7m represents a practical maximum.

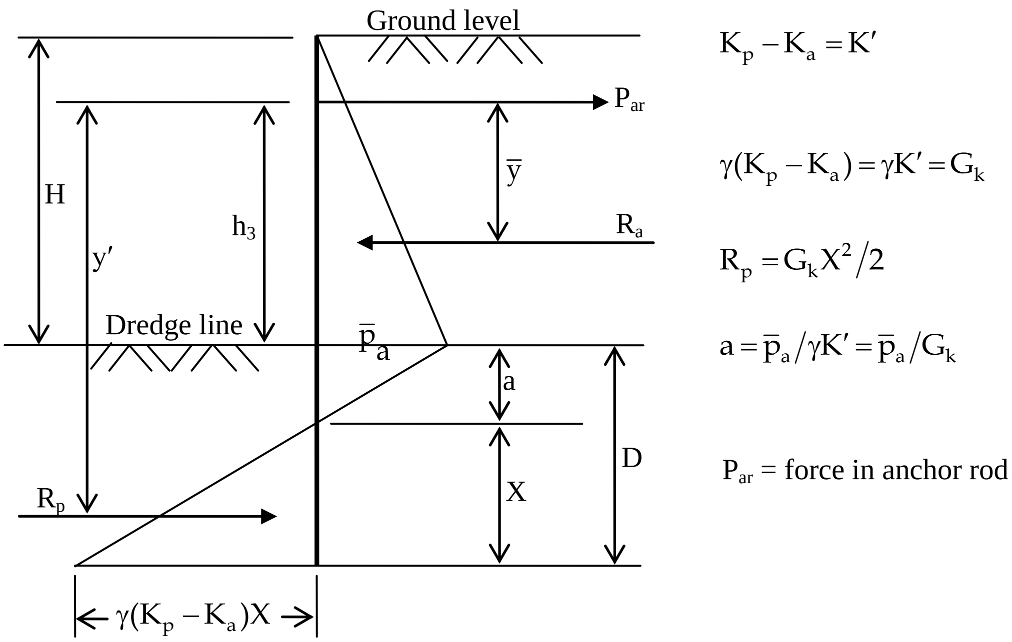

Figure 1. Pressure distribution diagram for anchored sheet pile in cohesionless soil, using the conventional method

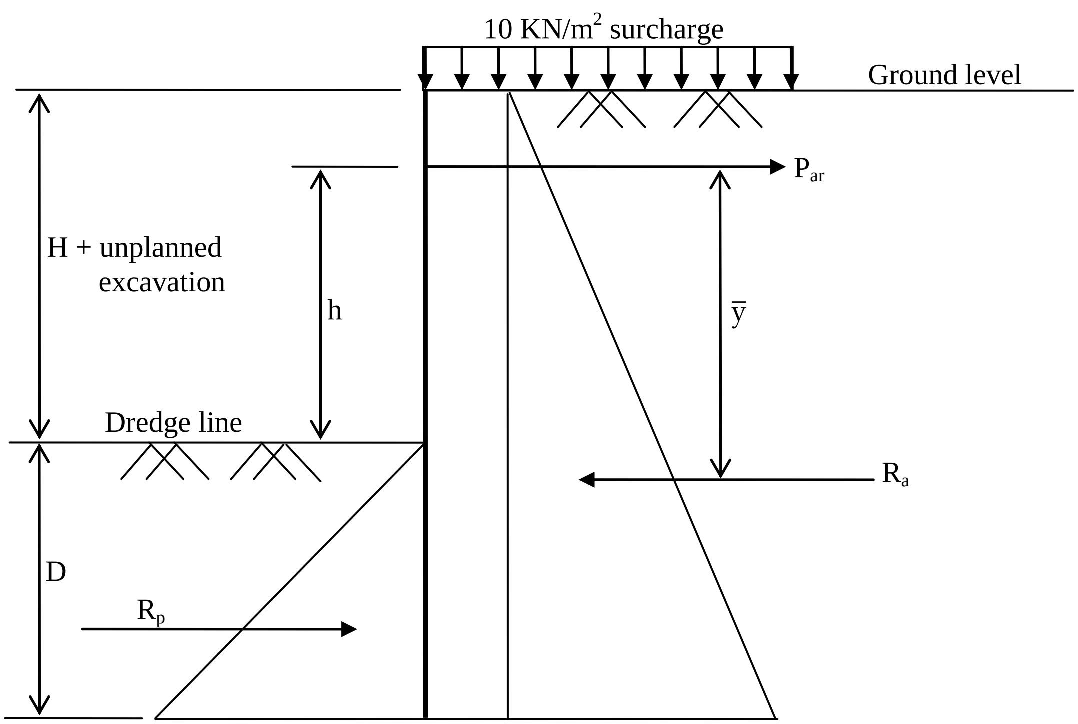

Figure 2. Pressure distribution diagram for anchored sheet pile in cohesionless soil, using the BS8002 method

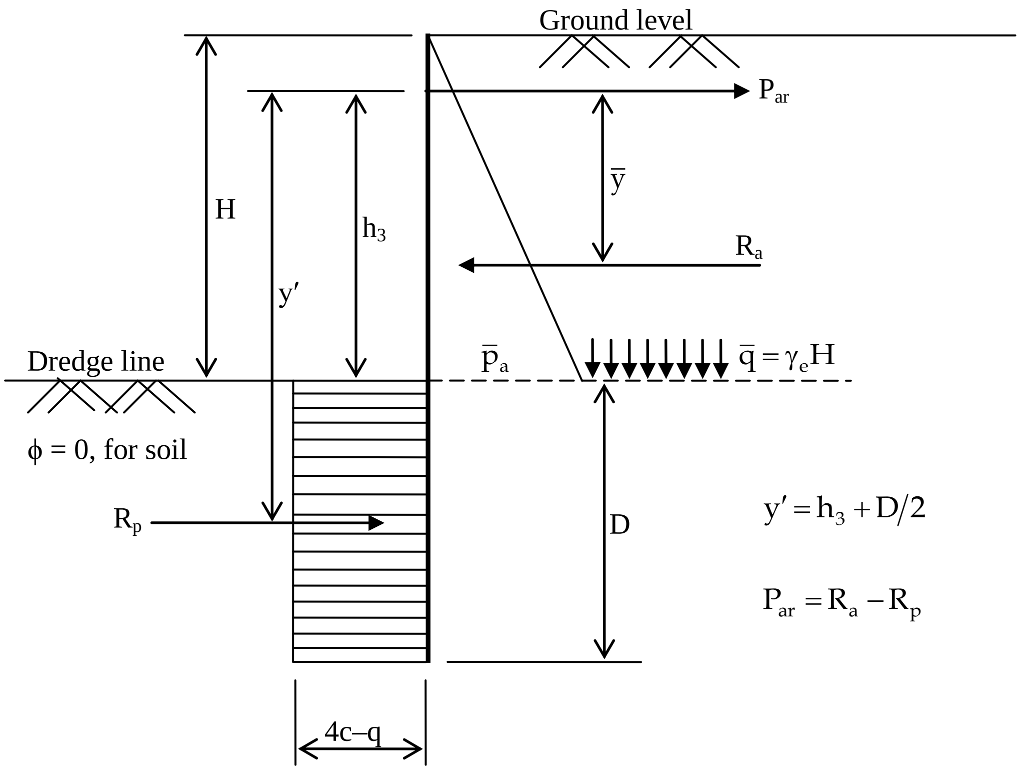

Figure 3. Pressure distribution diagram for an anchored sheet pile in cohesive soil

Table 1. Results for the design of anchored sheet pile in cohesionless soil

Method used	Design parameters	Embedment depth, D (m)	Factor of safety	Anchor rod force, P_{ar} (KN)	Total length of pile (m)
Conventional (CECP2) (a) Increasing computed depth by 30% (b) Reducing K_p by a factor (i.e. using $K_p/1.5$)	Retained height = 8.0 m. Anchor point is 1m below top of pile. γ =18 KN/m^3 ϕ = 30^o δ = 20^o	2.52 2.53	2.04 1.53	30.3 87.06	10.52 10.53
BS8002 approach based on taking different trial depths and subsequently checking equilibrium	Retained height = 8.7 m (i.e. 8.0 m + 0.7m unplanned excavation). γ =18 KN/m^3 Design ϕ = 25.7^o δ = 19.8^o	2.8 3.0 3.5 3.7	1.00 1.10 1.30 1.46	141.43 113.07 57.28 7.57	11.5 11.7 12.2 12.4

Table 2. Results for the design of anchored sheet pile in cohesive soil

Method used	Design parameters	Embedment depth, D (m)	Factor of safety	Anchor rod force, P_{ar} (KN)	Total length of pile (m)
Conventional (CECP2) (a) Increasing computed depth by 40% (b) Reducing the cohesion term by a factor (i.e. using c/1.5)	Retained height = 9.0 m. Anchor point is 1m below top of pile. For granular backfill, ϕ = 30^o and γ = 16.5 KN/m^3. Below dredge line ϕ = 0 and c = 72.0 KN/m^2	1.12 2.53	1.3 3.2	75.51 85.11	10.12 11.35
BS8002 approach based on taking different trial depths and subsequently checking equilibrium	Retained height = 9.8 m (i.e. 9.0 m + 0.8m unplanned excavation). For granular backfill, design ϕ = 25.7^o, γ =16.5 KN/m^3. Below dredge line ϕ = 0 and c = 72.0 KN/m^2	1.55 1.70 2.0 2.3 2.5	1.0 1.11 1.3 1.5 1.7	113.6 96.2 61.27 26.38 3.12	11.35 11.5 11.8 12.1 12.3

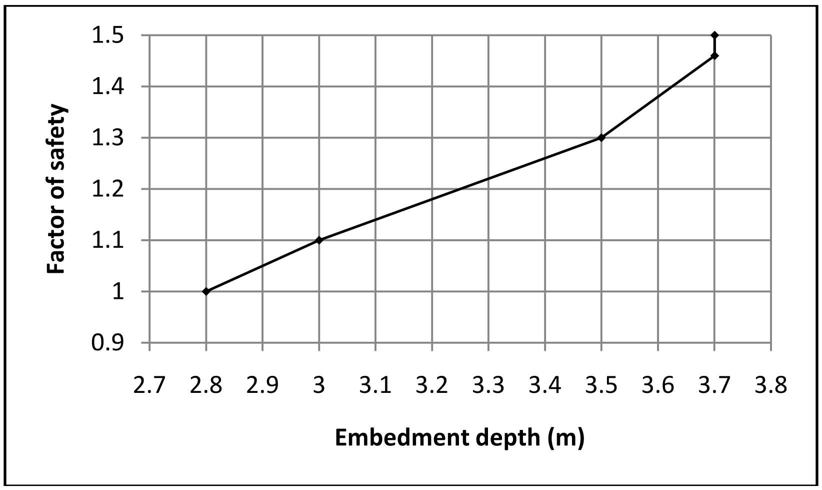

Figure 4. Variation of safety factor with embedment depth in granular soils - BS8002 method

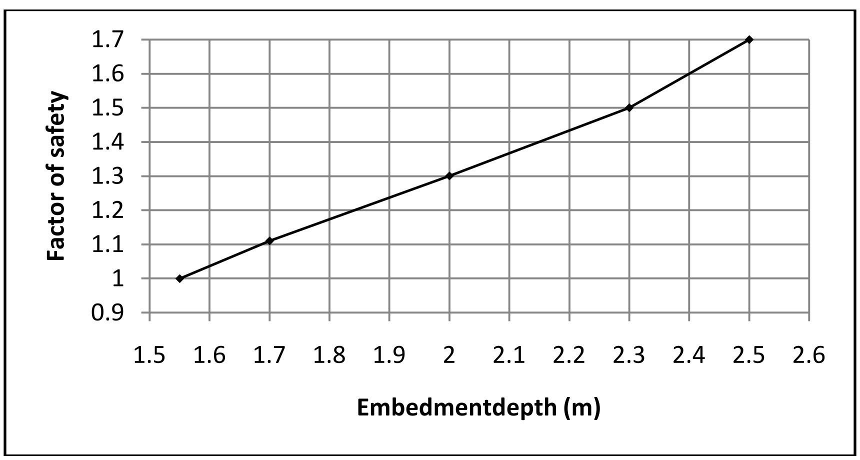

Figure 5. Variation of safety factor with embedment depth in cohesive soils - BS8002 method

In Table 2 dealing with embedment in cohesive soils the results show that the use of the conventional methods based on CECP2 and its variants gives greatly varying embedment depths depending on whether the factor of safety is applied to the computed depth or the cohesive term. Also the values of the F.S. obtained using the conventional methods differ greatly. On the other hand using the BS8002 approach assuming the worst credible loading results in an embedment depth approximately intermediate between the values given by the conventional methods, for the situation or condition when the factor of safety is unity. However for this equilibrium of moments condition, the force in the anchor rod is relatively large.

From Table 2 it is apparent that using the BS8002 approach and increasing the embedment depth, the F.S. increases gradually while there is a corresponding decrease in the anchor rod force. It can be inferred that the wall becomes more stable with increase in the embedment depth, but this also leads to an increase in the overall length of the pile making it less economical. The graph of factor of safety against embedment depth in Figure 5 shows that the factor of safety increases almost linearly with increase in embedment depth for the BS8002 method.

In summary from the results in Tables 1 and 2 it is apparent that for both granular and cohesive soils the BS8002 approach appears consistent since greater embedment depths lead to higher factors of safety but a corresponding decrease in the force of the anchor rod.

4. CONCLUSIONS

The present study sets out to investigate the applicability of the BS8002 limit state approach in addition to the conventional methods of CECP2 and its variants to the analysis and design of anchored sheet piles in granular and cohesive soils. From the results of the study the following conclusions have been drawn.

a) In the case of granular soils, use of the conventional procedures of either increasing the computed depth by 20% to 40% or applying a reduction factor to the coefficient of passive resistance will result in very similar embedment depths, but give rise to markedly different factors of safety. The BS8002 design approach in comparison produces only a relatively moderate increase in embedment depth, but lower factor of safety.

b) In the case of cohesive soils, the conventional methods give rise to greatly varying embedment depths depending on whether the factor of safety is applied to the computed depth or the cohesion term. In addition the calculated factors of safety using the conventional methods greatly differ. In contrast the BS8002 approach (for F.S. = 1.0) produces an embedment depth approximately intermediate between the estimates given by the conventional methods. Also for the equilibrium of moments condition, the BS8002 value of anchor rod force is relatively large.

c) The BS8002 design approach suggests that the factor of safety increases fairly linearly with increase in embedment depth for both granular and cohesive soils. However there is a corresponding decrease in the anchor rod force. The BS8002 method appears to be consistent in these respects. Notwithstanding, in the case of granular soils there appears to be an optimum embedment depth for anchored sheet piles beyond which any further depth increase becomes impractical.

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