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Observations on the Design of a Typical Anchored Sheet Pile in Cohesionless Media using the Conventional CECP2 and the BS8002 Design Methods

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ABSTRACT

In the present study a comparison of two alternative designs of a typical anchored sheet pile in cohesionless media whose soil design parameters had been previously established through appropriate site and laboratory investigations is carried out. The designs have been executed using the conventional Civil Engineering Code of Practice CECP2 - Earth Retaining Structures and the Code of Practice for Earth Retaining Structures - BS8002 based on limit state procedures. It was found that the BS8002 method yielded a higher depth of penetration and a larger anchor rod force compared to the CECP2 approach. This was felt to be due to the BS8002 procedure which stipulates an additional surcharge load of 10 KN/m^2 as well as an additional unplanned excavation of approximately 10% of the height between the dredge level and the position of the anchor rod.
Keywords: Anchor, pile, cohesionless, design, embedment, depth.

INTRODUCTION

The use of sheet piles has grown in popularity over the past six decades or more due to the great technological strides that have taken place coupled with the ever increasing economic, social, urban and developmental needs that have arisen. Cantilever sheet piles are generally used as temporary structures in civil engineering construction, and are employed for moderate heights only. Anchored sheet piles on the other hand are extensively used in water- front or marine construction, where the water table is high or the soils encountered are soft. The stability of such walls is catered for by the passive resistance developed in front of the wall as well as the anchor rod forces. The latter assists in reducing the embedment depth, lateral deflection and bending moments in the wall.

Various methods of analysis and design of cantilevered and anchored sheet piles have evolved and an overview of the more significant developments is provided by Craig [1]. One of the more popular conventional methods that have been applied extensively with some measure of success is that represented by the conventional Civil Engineering Code of Practice CECP2 code [2]. The method employs a lumped parameter approach whereby the factor of safety is expressed in terms of the ratio of restoring moments to overturning moments. The depth of penetration is determined from a stability assessment based on the limiting equilibrium method of analysis in which conditions of failure are postulated and a factor of safety applied to ensure that such a failure does not occur. This is done by using a multiplying factor to increase the depth of penetration from that required by limiting equilibrium.

A more recent approach is that contained in the Code of Practice for Earth Retaining Structures BS8002 [3] which incorporates limit state design principles. The BS8002 method sets out to determine the most unfavourable or the most onerous loading conditions. In order to summarize the major changes incorporated in BS8002 in comparison to CECP2 it should be noted that retaining wall design to BS8002 is to be based on an effective stress analysis if the wall is to be a permanent structure, however for temporary walls an undrained analysis has to be undertaken. Secondly, although BS8002 adopts a limit state philosophy it avoids the use of partial safety factors. In contrast CECP2 uses factors of safety. Thirdly design based on BS8002 is for serviceability. This fact according to Akroyd [4] is necessary because the maximum earth pressures occur during working conditions when there is minimum movement of the wall. CECP2

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in comparison bases design on the ultimate limit state whereby factors of safety are adopted to guard against failure at this state. Fourthly, for design, BS8002 uses a fraction of the peak soil strength for earth pressure calculations when dealing with soil parameters such as cohesion c or angle of shearing resistance ϕ. Akroyd [4] has opined that due to the need to achieve a satisfactory wall in service the movement of the wall must be relatively small. Since strains in the soil mass are small, the design procedure takes account of this by using a fraction of the peak strength. In contrast the CECP2 approach recommends the use of the actual strength. Furthermore in BS8002, a minimum surcharge of 10 KN/m^2 is stipulated at ground level behind the wall. Finally, a required 0.5 m over-dig level or not less than 10% of the total height retained is specified in order to provide for accidental and unforeseen events.

Apart from the methods and design procedures outlined in CECP2 and BS8002, several prominent investigations and developments in design methods as well as studies on the stability performance of earth retaining structures in service have occurred over the past six decades [5–16]. Powrie [14, 15] investigated embedded retaining walls analysed using the limit equilibrium approach and dealt with parameters such as soil strength, soil-wall friction and safety factors, all of which had generated controversies in the past. The aim of his research was to expound a rational basis for the selection of soil parameters and factors of safety for use in conventional limit equilibrium analysis of embedded retaining walls. He concluded that critical factors were the identification of the most onerous loading condition and consideration of groundwater effect as well as the selection of appropriate soil parameters and factors of safety.

It is clear from a review of recent developments [8, 14, 16] that some uncertainties and controversy still remain in respect of the analysis and design of embedded walls, and the use of the various factors referred to earlier with reference to the conventional CECP2 method and the limit state BS8002 approach. The present study has consequently been directed at the design of a typical anchored sheet pile wall in marine conditions using real soil design parameters whose values have been determined through relevant site and laboratory investigations. Designs have been performed using both the conventional CECP2 and the limit state BS8002 methods and the results of both approaches have been compared.

METHODOLOGY

A schematic for the anchored sheet pile and the surrounding soil medium is shown in Figure 1. The position of the anchor rod force has been pre-set at 0.5 m from the top off the sheet pile in accordance with the dictates of a local consultancy. The water table is located at 2.8 m below ground level and the dredge line is 4.4 m below the water table. It is required to determine the embedment depth, the total length of pile and the force in the anchor rod. A surcharge of 25 KN/m^2 behind the retained soil mass at ground level has also been stipulated by the local consultancy.

The idealized pressure distribution diagram based on the conventional CECP2 method in the presence of water in the backfill is shown in Figure 2. Following Bowles [17] and Murthy [18], the depth of penetration of the sheet pile below the point of zero pressure is given by

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

Also the force in the anchor prop is given by the expression

$$F_a = R_a - R_p \tag{2}$$

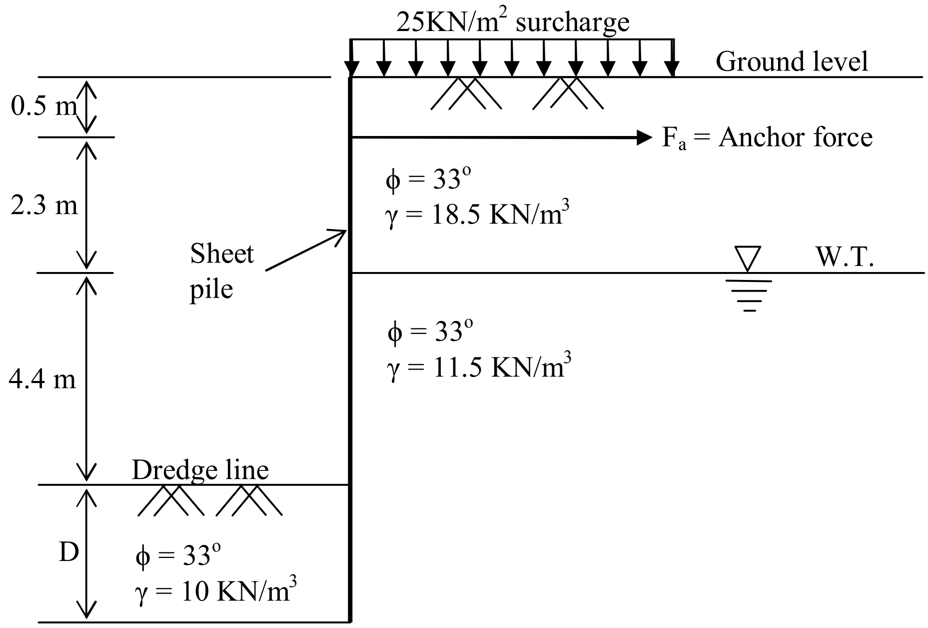

Figure 1. Schematic of the anchored sheet pile and the surrounding soil

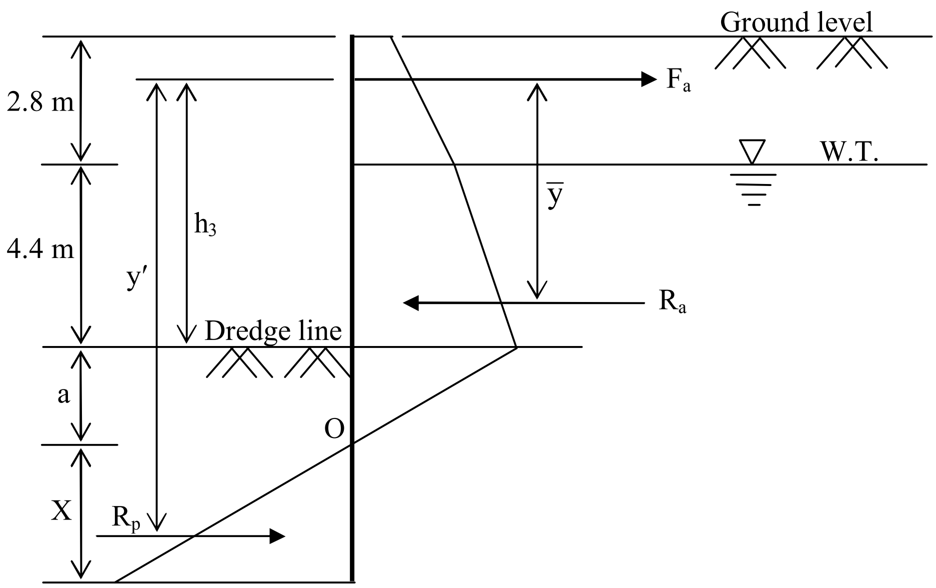

Figure 2. Pressure distribution diagram using the conventional CECP2 method

If the BS8002 design approach is used, the pressure distribution diagram is shown in Figure 3. The moment equilibrium relationship is obtained by taking moments about the anchor rod position, thus yielding

$$R_a\bar{y} - R_p y' = 0 \tag{3}$$

where $y' = 0.67D + h$, and D represents the minimum computed embedment depth. A similar relationship to equation (2) is used for horizontal equilibrium.

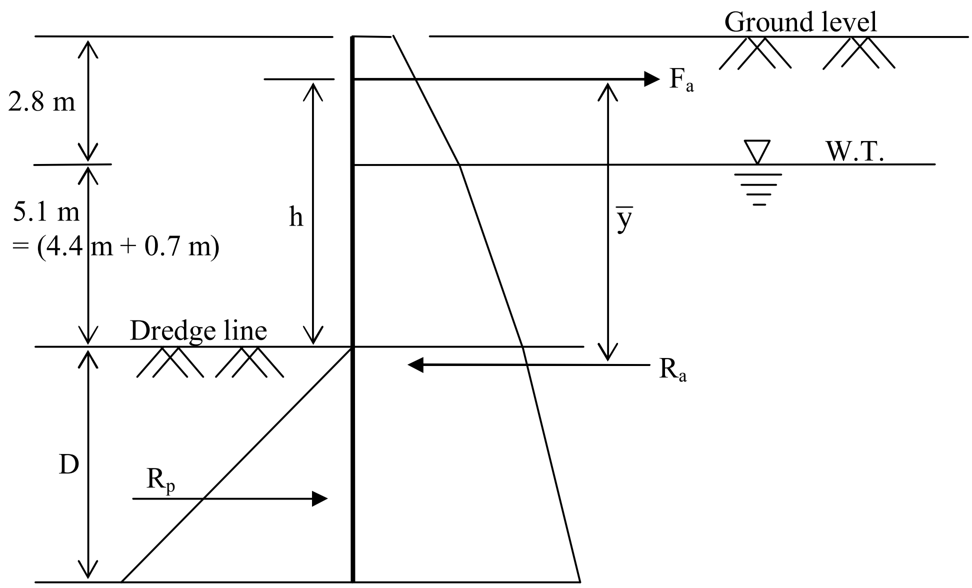

Figure 3. Pressure distribution diagram using the BS8002 design method

RESULTS AND DISCUSSION

A comparison of the results of the design of the anchored sheet pile wall using the two design codes is shown in Table 1. For this purpose the CECP2 computed depth has been increased by 30% to obtain the embedment depth shown. In conventional CECP2 design an embedment factor of between 1.20 and 1.40 is considered normal, so the 30% increase applied in Table 1 is not out of place. It is obvious that a higher depth of penetration, by a margin of about 21%, is obtained using the BS8002 method compared to the conventional CECP2 approach. Franklin and Olopade [19, 20] in earlier studies on cantilever and anchored sheet piles in both cohesive and cohesionless soils found that greater embedment depths by margins of about 12% were obtained for granular soils when using BS8002 as opposed to the conventional CECP2. For cohesive soils, differences between the two design methods were found to be well above 20% in some cases. The differences in the current investigation, as observed also in the previous studies mentioned, are most probably due to the BS8002 design specification of an additional surcharge load of 10 KN/m^2 thereby increasing the design surcharge to 35 KN/m^2. Another likely contributory factor in the present case is the additional unplanned excavation of 0.7 m which represents about 10% of the height between the dredge line and the anchor rod (6.7 m for the present case). All these according to BS8002 represents the most unfavourable or onerous loading condition. It should be noted at this juncture that Craig [1] does not recommend the use of an embedment factor as applied in CECP2 on the grounds that the introduction of such a factor is somewhat empirical. If such a factor were to be utilized it is recommended that the CECP2 design should be checked by an alternative method.

The force in the anchor rod according to BS8002 is approximately 75% to 80% larger than the conventional CECP2 estimate. In addition the total length of the pile according to BS8002 is about 14% in excess of the CECP2 value. Again both these differences can be attributed to the radically different approach adopted by BS8002 for embedded walls compared to CECP2.

As a final remark it should be emphasized that no attempt is being made here to generalize the findings of the present investigation. The latter should be viewed as being somewhat related to the problem at hand and the results may not be specifically applicable to other design scenarios with different soil parameters and varying groundwater conditions. Nevertheless it is still generally true that the BS8002 estimates of both embedment depths and anchor rod forces are likely to be in excess of those recommended by CECP2 on the premise that BS8002 sets out deliberately to base designs on the most severe and unfavourable loading conditions rather than for example, the utilization of factors of safety in a manner as suggested by CECP2 which ultimately bears little relationship to service load behaviour [4].

Table 1. Comparison of results obtained using the conventional CECP2 and the BS8002 methods

Design details	Conventional CECP2	BS8002 design
Active force R_a (KN/m run)	193.18	617.05
Passive force R_p (KN/m run)	175.20	423.50
Computed depth (m)	3.495	5.50
Embedment depth (m)	4.540	5.50
Overturning moment (KNm/m)	808.95	4689.58
Restoring moment (KNm/m)	1767.77	4694.50
Factor of safety	2.19	1.00
Anchor force (KN)	107.71	193.55
Pile length (m)	11.74	13.40

CONCLUSIONS

From the results of the present study which involves the design of an anchored sheet pile in a cohesionless medium based on real soil design parameters, the following conclusions may be drawn.

(1) The BS8110 design method produces a higher penetration or embedment depth than the conventional CECP2 approach by a margin of about 21%.

(2) The BS8002 estimate of force in the anchor rod is about 75% to 80% larger than that given by CECP2.

(3) The observed differences between the results of BS8002 and CECP2 in respect of embedment depth and anchor rod force are felt to be due to the more stringent loading conditions stipulated by BS8002 for the design of embedded walls.

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