A NOTE ON THE ANALYSIS AND DESIGN OF CANTILEVER RETAINING WALLS USING THE CECP2 AND BS8002 METHODS

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ABSTRACT

The aim of the present study was to compare and contrast the results of the conventional CECP2 method and its variants with the limit state design approach of BS8002 when applied to a reinforced concrete cantilever retaining wall. It was found that in all cases stability against sliding and overturning was achieved. However using the CECP2 code in conjunction with safety factors recommended by BS8110, stability against sliding was achieved only with the use of a heel beam. In contrast with the BS8002 approach which utilizes the most onerous loading condition, there was no need for a heel beam. With respect to bearing pressure analysis, use of the CECP2 method resulted in maximum bearing pressures being below the allowable bearing value. In contrast with BS8002, maximum bearing pressures were less than the allowable only when the design angle of shearing resistance ϕ was high, a situation corresponding to angular soil particles. It was concluded that only under such a condition would BS8002 produce a more economical design.

Keywords: *Cantilever, wall, stability, sliding, overturning, bearing, pressure, factor, safety.*

1. INTRODUCTION

Earth retaining structures are ubiquitous in the man-made environment. However, notwithstanding, their use has increased enormously in recent decades due to the great advance in technological, social and economic developments that have occurred. Reinforced concrete cantilever retaining walls are considered to be more economical in comparison to their traditional mass concrete or masonry gravity wall counterparts. This is because unlike the latter whose material is used solely for its dead weight, in cantilever walls the backfill itself contributes significantly towards the required dead weight. As a consequence the concrete stem can be made relatively more slender thus, in addition, enhancing the visual appearance and aesthetics of the structure.

Corresponding to the greatly increased usage noted above has been an increased development in analysis and design methods with respect to earth retaining structures of various types. An excellent summary of some of the significant developments is provided by Craig [1]. The CECP2 code [2] represents one of the very popular conventional methods which has been applied reasonably successfully to retaining structures. The BS8110 design code [3] for reinforced concrete structures has also been utilized in conjunction with CECP2in the quest for satisfactory analysis and design solutions. Despite the previous comments however it has been observed that the CECP2 approach possesses a number of shortcomings and might not yield reliable nor accurate results in several cases [4]. An alternative and more recent method represented by the BS8002 code [5] embodies limit state principles to an extent and marks a sharp deviation from the conventional approach of CECP2. However the existence of two widely used and apparently conflicting methods has generated further observations as well as controversy in respect of appropriate procedures for analysis and design of earth retaining structures.

As a result of the foregoing developments the present investigation was embarked upon. The primary objective was to compare and contrast the results of analysis and design of a typical reinforced concrete cantilever retaining wall using both the CECP2 and BS8002 codes. The approach utilized has been mainly theoretical and case studies and investigations of existing walls have been avoided. However the soil design parameters that have been adopted for this purpose are typical of those employed locally [6].

2. METHODOLOGY

The design of a reinforced concrete cantilever retaining wall according to CECP2 in conjunction with BS8110 involves several considerations. Firstly stability analysis is based on the ultimate limit state, the critical condition being when a maximum horizontal force acts with a minimum vertical load. In order to guard against a stability failure, a safety factor $\gamma_f = 1.6$ will be applied. Secondly the bearing pressure analysis is based on the serviceability limit state.

In the BS8002 methodology, a fraction of the peak strength of the soil is used. Although limit state philosophy is adopted, partial safety factors are not employed. The design earth pressures are based on those which occur at serviceability. The design including stability against sliding and overturning is carried out using a mobilization factor M. A minimum value of M = 1.2 is specified for both angle of shearing resistance ϕ and cohesion c, for drained conditions in the soil. In addition the design value of the angle of wall friction δ will be taken as $\tan^{-1}(0.75\tan\phi)$. Furthermore a compulsory 0.5 m over-dig level is imposed in addition to a minimum 10 KN/m^2 surcharge. No further factors of safety are necessary because according to BS8002 the design is based on the worst case scenario.

The comparative design is done using the cantilever retaining wall shown in Figure 1. The wall supports a granular material of unit weight 19.6 KN/m^3 and the allowable bearing pressure is 110 KN/m^2. The height of the soil to be retained is 4.5 m and the thickness of the base slab is 0.4 m. The width of the base slab is 3.4 m and the toe projection is set at 0.8 m. These dimensions represent that of a typical cantilever retaining wall. For the present study an angle of shearing resistance $\phi = 30^o$ has been adopted.

With BS8002 it is necessary to consider soil properties as stipulated in the code in order to determine the design ϕ. The latter depends on soil properties such as angularity of the soil particles, the grading of the particles and the results of standard penetration tests, all expressed in degrees. Analysis was carried out by varying the soil properties and choosing the appropriate ϕ value, and subsequently the design ϕ and other design parameters. The maximum or peak ϕ is given by

$$\phi_{max} = \phi + A^o + B^o + C^o \quad (1)$$

where A, B and C depend on the angularity of soil particles, the grading and the standard penetration test results in that order. The design ϕ is given by

$$\text{design } \phi = \tan^{-1}[(\tan\phi_{max} / M)] \quad (2)$$

where M is the mobilization factor. In all cases the value of C is taken as 2^o for sand/gravel soil, implying less than 20 blows in the standard penetration test. In line with BS8002 methodology, the shear strength is taken as the lesser of the peak strength divided by the mobilization factor or the critical state strength.

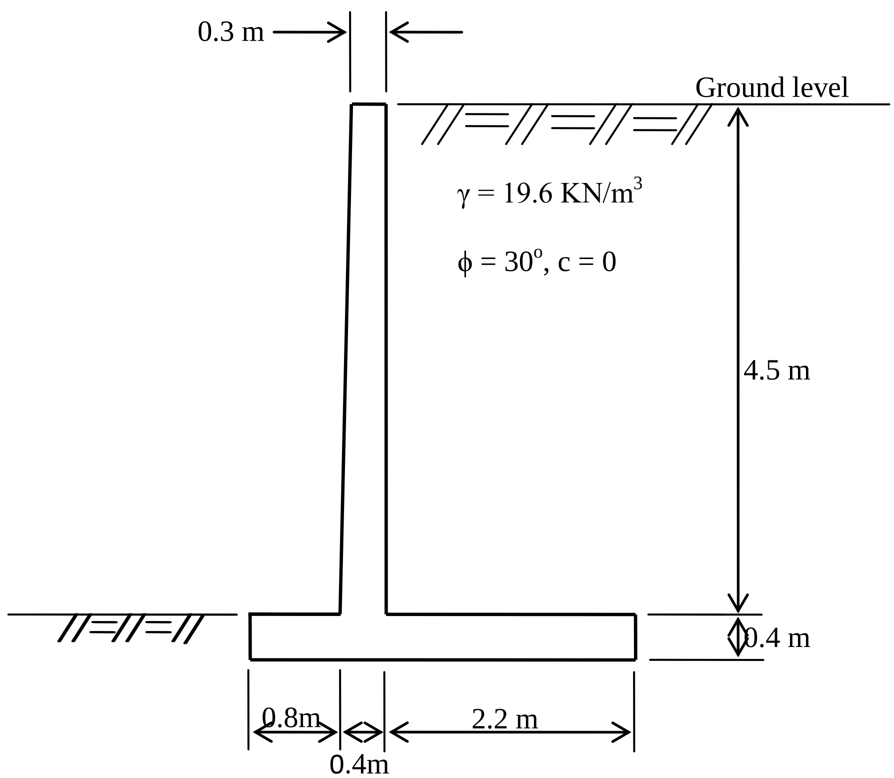

Figure 1. Schematic of reinforced concrete cantilever retaining wall

3. RESULTS AND DISCUSSION

The results of the analysis and design of the cantilever retaining wall in granular soil for both the conventional CECP2 code used in conjunction with BS8110, and the BS8002 approach, are shown in Table 1. With reference to the design parameters in respect of both codes, every attempt has been made to ensure uniformity in order to assist the comparative study. It is obvious from Table 1 that both design methods give varying results, a situation attributed to the differences in design procedures.

Examination of Table 1 reveals that for both codes in all cases, stability against sliding and overturning is achieved. More specifically however, using the conventional CECP2 approach coupled with the safety factors stipulated by BS8110, stability against sliding is achieved only with the provision of a heel beam. In comparison if the BS8002 design method is used, no allowance for a heel beam need be made despite the code's insistence on the most onerous loading condition. Interestingly for the bearing pressure analysis using the conventional CECP2 method, maximum bearing pressure for this specific case is less than the allowable bearing pressure. In contrast for the BS8002 approach, maximum bearing pressure is less than the allowable value provided the design ϕ is very high, a situation that corresponds to the use of angular soil particles. For values of design ϕ less than 33^o approximately, maximum bearing pressures always exceed the allowable values. Since the value of the maximum bearing pressure is primarily dependent only on the backfill and load above the base, and not on the soil below the base slab, it can be inferred that the use of angular soil particles for the present case should result in a more economical design for the cantilever wall.

The relationships between the design parameters A, B and ϕ and the factors of safety against sliding and overturning are shown in Figures 2 and 3 respectively. The ratio $(A+B)/\phi$ is a dimensionless parameter, and the graphs demonstrate that stability of the wall in respect of sliding and overturning increases with increase in this dimensionless parameter.

Table 1. Results of cantilever retaining wall design in respect of CECP2/BS8110 and BS8002 codes

Soil properties	Design parameters	Stability against overturning (*)	Stability against sliding (**)	Bearing pressure analysis (***)
Conventional method using CECP2 in conjunction with BS8110				
No provision for angularity or the grading of particles	Design $\phi = 30^o$ Design $\delta = 20^o$	540/172.2 = 3.14 Satisfied	107.1/105.4 = 1.02 Satisfied with a heel beam provided	110/86.9 = 1.27 satisfied
BS8002 method				
Rounded particles A = 0^o Uniform grading B = 0^o, C = 2^o.	$\phi_{max} = 32^o$ Design $\phi = 27.5^o$ Design $\delta = 21.3^o$ $(A + B)/\phi = 0$	643.9/204.7 = 3.15 Satisfied	121.8/105.3 = 1.16 Satisfied	110.0/132.1 = 0.83 Not satisfied
Rounded particles A = 0^o Moderate grading B = 2^o, C = 2^o	$\phi_{max} = 34^o$ Design $\phi = 29.3^o$ Design $\delta = 22.8^o$ $(A + B)/\phi = 0.07$	643.9/184.9 = 3.48 Satisfied	131.6/95.10 = 1.38 Satisfied	110.0/122.5 = 0.90 Not satisfied
Sub-angular particles A = 2^o Moderate grading B = 2^o, C = 2^o	$\phi_{max} = 36^o$ Design $\phi = 31.2^o$ Design $\delta = 24.4^o$ $(A + B)/\phi = 0.13$	643.9/176.3 = 3.65 Satisfied	141.6/88.3 = 1.60 Satisfied	110.0/116.1 = 0.95 Not satisfied
Angular particles A = 4^o Moderate grading B = 2^o, C = 2^o	$\phi_{max} = 38^o$ Design $\phi = 33.1^o$ Design $\delta = 26.1^o$ $(A + B)/\phi = 0.18$	643.9/158.4 = 4.07 Satisfied	152.9/81.5 = 1.88 Satisfied	110.0/109.6 = 1.00 Satisfied

(*) Stability = Restoring moment/Overturning moment
(**) Stability = Frictional resisting force/Sliding force
(***) Stability = Allowable bearing pressure/Maximum bearing pressure

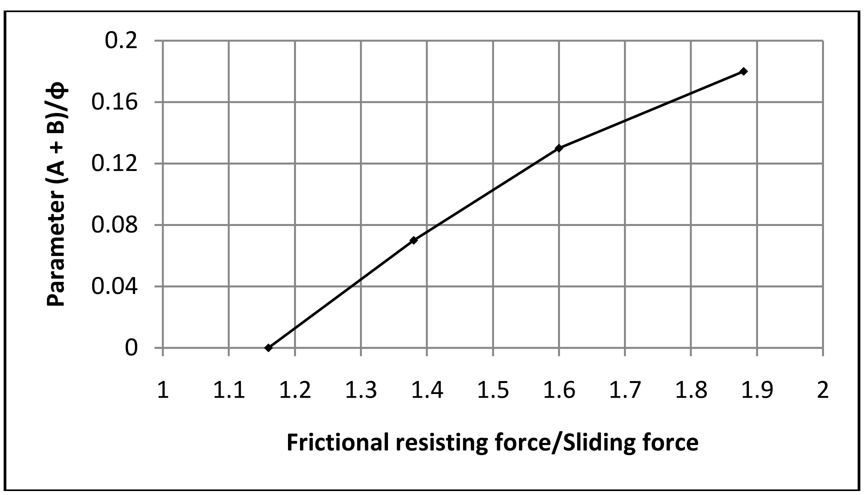

Figure 2. Relationship between design parameters (A, B, and ϕ) and factor of safety against sliding

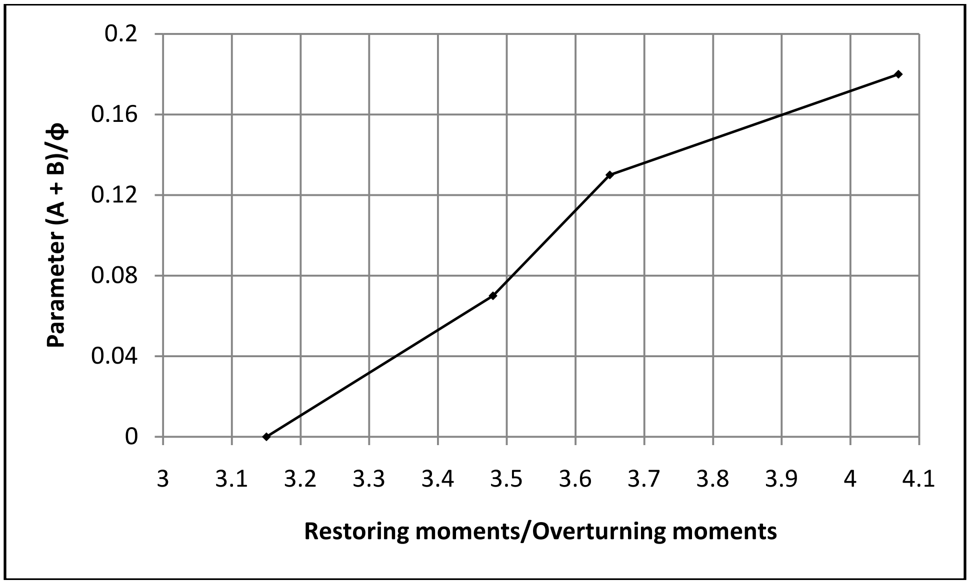

Figure 3. Relationship between design parameters (A, B, and ϕ) and factor of safety against overturning

4. CONCLUSIONS

In the present study, the CECP2 and BS8002 methods have been applied to the analysis and design of a typical cantilever retaining wall supporting a granular backfill. Representative values of soil design parameters have been employed for this purpose. From the results presented, the following conclusions have been reached.

a) With the CECP2 method used in tandem with BS8110, stability against sliding is achieved only with the provision of a heel beam. In contrast with the BS8002 approach, despite its insistence on the most onerous loading conditions, the need for a heel beam is found to be unnecessary.

b) For the specific design case studied, maximum bearing pressures are below the allowable value when the CECP2 method is used. On the other hand with the BS8002 approach, the bearing pressure criterion is satisfied only when the design angle of shearing resistance ϕ is high, a condition which corresponds to the use of angular soil particles.

c) For the BS8002 method, the stability of the wall in relation to sliding and overturning increases with increase in the dimensionless parameter (A + B)/ϕ.

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