Effect of Limited Backfill on the Lateral Pressure Distribution on Cantilever Retaining Walls in Clays

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Summary When retaining walls are constructed in cohesive soils, a zone behind the retaining wall is excavated and backfilled with well-draining granular material to prevent the build up of water and to reduce the lateral pressures acting on the wall. Use of classical theories to predict the magnitude and distribution of lateral pressures acting on the wall presents a number of questions for which the designer relies on experience and judgement for guidance. Examples of these questions are the choice of appropriate soil parameters to use to compute the lateral earth pressures, the choice and significance of the extent of backfilled zone and the effect of the type and stiffness of the retaining wall chosen.

Numerical analyses, such as the finite element method would address all the above questions readily, provided suitable data is available, although the analyses would only be undertaken for large construction projects. For routine design, however, where the overall costs are not so high, the time and costs involved in executing a good soil investigation, let alone a numerical analysis, is usually out of the question. Accordingly, the designer has to rely on experience to select suitable design parameters and design charts to estimate the likely behaviour of the retaining wall.

This paper presents results of numerical studies, in the form of charts, for estimating the effect of a limited backfill on the earth pressures developed on cantilever retaining walls supporting cohesive soils.

1. INTRODUCTION

The use of classical earth pressure theories of Coulomb and Rankine is widespread, especially in routine designs involving small projects and costs, although these analyses may not always be suitable or valid representation of field conditions. The best example is where cantilever retaining walls are used to retain natural clay soils, and granular, cohesionless material is placed adjacent to the wall to prevent any build up of hydrostatic pressures behind the wall, as well as to reduce the lateral earth pressures. This case is illustrated in Bowles (1988) who recommended that the lateral pressure distribution should be estimated using the at rest coefficient of lateral earth pressure, K_o.

Accurate predictions of the lateral pressure distribution on the retaining wall are difficult because of a lack of adequate data on: the stiffness and strength of the natural cohesive soil; the interactions of the movements of the backfill and the natural soil, especially during construction; and the overall instability of the soil and retaining wall during its design life. In spite of these gaps in knowledge, the designer is expected to use experience and judgement to choose suitable pressure distributions for use in design.

Numerical studies utilising the finite element method have been undertaken to quantify the influence of the extent of the backfill on the lateral pressure distribution behind cantilever retaining walls. In our studies, a loose backfill has been assumed, although it is accepted that over-compaction leads to larger lateral pressures behind the wall. The choice of clay properties has been based on average soil properties, with the clay grouped into soft, medium, stiff, and very stiff, clay, has been adopted.

2. THE FIELD PROBLEM

In situations that involve construction of cantilever retaining walls to retain clays, backfill consisting of well-draining material is required. The extent of excavation for the backfill zone, and its effect on the lateral pressures developed on the retaining wall is usually based on the rupture surface that would develop through the backfill material. The inclination of the potential rupture plane to the horizontal, $\theta = 45 + \phi/2$, is used to estimate the extent of the trapezoidal backfill zone. In many instances, the costs involved do not warrant such extensive construction and rectangular or triangular backfill zones are adopted. The dimensions of the cantilever retaining wall used were H = 4.5 m, H1 =

4.1 m, and B = 3.4 m. These dimensions are identical to those used by Goh (1993).

As shown in Figure 1, the extent of (a) the triangular backfill zone, from the bottom of the stem, is characterised by a top width, ***a***; (b) the rectangular backfill zone is characterised by a base width, ***b***; and (c) the trapezoidal backfill zone is defined by a base width, ***B***, and top width, ***c***. The choice of the width of the triangular, rectangular or trapezoidal backfill zone will affect the development of the lateral earth pressures on the retaining wall and the overall stability of the wall. Analyses within the range of ***a***/H and ***c***/H = 0.1 to 2.0, and ***b***/B = 0.1 to 1.0 were carried out for the cantilever retaining wall.

In addition to the effects of differences in shear strength and stiffness parameters of the natural soil deposit and the backfill, the geometry of the backfill zone will affect (i) the settlement and rotation of the retaining wall, (ii) the movements of the natural soil, and (iii) the overall stability of the retaining wall and natural soil. This paper concentrates on the evaluation of the lateral pressures acting on the wall, that are required for the structural design of the wall, since stability analyses for the wall can be readily performed once the horizontal forces are evaluated.

3. NUMERICAL ANALYSES

In the finite element analyses, the model dimensions were chosen to correspond to those likely to be encountered in many field situations. Roller constraints were assumed at horizontal distances of 8H behind the wall, 2H in front of the wall, and 2H beneath the wall, where H is the height of the wall. The backfill is located between the back of the vertical wall and the excavation surface. Details of the finite element mesh are given in Elchalakani and Kaggwa (1995). The mesh consists of 466 8-noded isoparametric elements and 1438 nodes. Approximately half the number of elements were concentrated in zones of high stress gradients behind and beneath the wall. Analyses were carried out on four different types of clay, having shear strength and stiffness parameters recommended by Bowles (1988). More detailed parametric studies, examining the relative importance of the width of the base with respect to the overall stability of the retaining wall, are not reported here. Parametric studies of the effects of shear strength and stiffness parameters of the backfill and the clay are also not included.

The soil was modelled as a linear elastic-perfectly plastic material with a Mohr-Coloumb yield surface, and an associated flow rule has been assumed. The wall was modelled to behave linearly elastic by assigning high values to the shear strength parameters compared to the stresses within the elements. Six-noded interface elements adjacent to the wall base and stem were used, similar to those employed by Clough and Duncan (1971), in order to model the interaction between the soil and the reinforced concrete wall. A high value was assigned

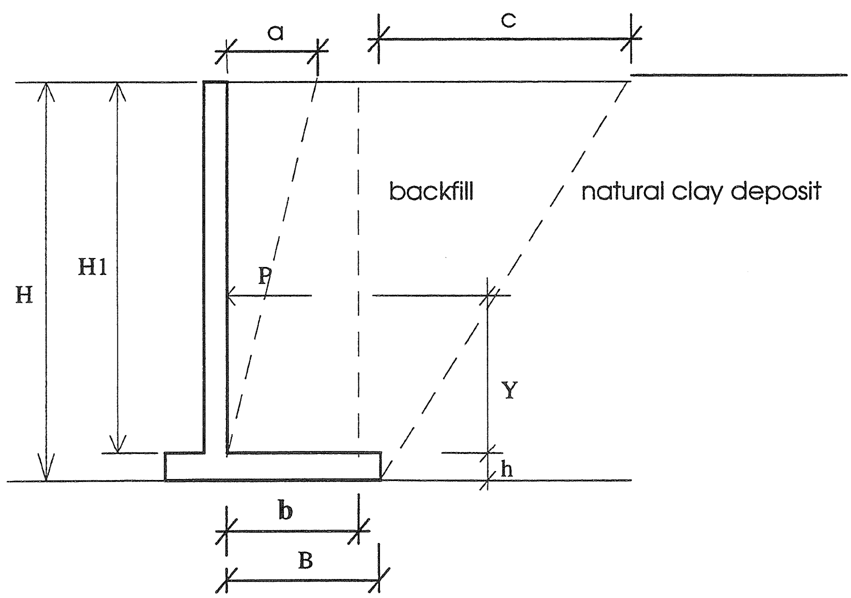


Fig. 1: Symbols used to define the geometry of the field problem

Table 1. Soil and concrete parameters used in finite element analyses

Material	c_u kPa	ϕ Deg.	γ kN/m^3	E MPa	ν
Soft Clay	25	0	16	2	0.49
Medium Clay	60	0	17	10	0.49
Stiff Clay	100	0	18	25	0.45
Very Stiff Clay	150	0	20	50	0.40
Sand	0	30	16	40	0.35
Concrete	1.E+9	40	22	25000	0.20

to the interface normal stiffness to prevent overlap of two adjacent two-dimensional solid elements.

In order to model a perfectly smooth wall the interface elements adjacent to the stem were assigned a relatively small shear stiffness of K_s = 0.001 MPa/m and angle of wall friction, δ, such that δ/ϕ = 0.76. The interface elements adjacent to the base were assigned relatively high values of K_s = 490 MPa/m, and shear strength parameters δ and c_a based on the ratios (δ/ϕ) =0.97 and (c_a/c) = 0.95.

The staged construction of the wall and the backfill was modelled using the technique proposed by Clough and Duncan (1971). The cohesionless backfill was modelled to be loosely placed, and the backfilling and casting of the wall were carried out in 10 lifts. In order to minimise computation time, the gravity of the backfill layers was directly switched on with no allowance for incremental loading of the soil.

4. EFFECT OF SIZE OF BACKFILL ON LATERAL PRESSURE

Lateral pressure distributions at the back of the wall, for stiff clay are shown in Figure 2. For steep cuts (a/H < 0.5) the lateral pressure distribution is uniform and generally less than the Rankine active values. In gentle cuts (a/H > 0.5) the lateral pressures were close to the Rankine active values in the upper two thirds of the wall and exceeded the Rankine active values in the lower third. These lateral pressures within the lower third are greater than the at rest earth pressures and approach the Rankine passive values.

The results demonstrate that, for triangular backfills, the wall characterisitcally rotates about the toe, with a maximum lateral deflection ratio was (Δ/H) = 0.032%, where Δ is the outward deflection and H is the height of the wall. For trapezoidal backfills, rotation was at the heel, and the maximum horizontal outward lateral deflection ratio was 0.024%. These values are less than those normally associated with active conditions, that are in the order of 0.1%, as reported, for example, by Goh (1993). Although the maximum lateral deflection was small, the lateral pressures in the upper part of the wall reach the Rankine active values, as shown in Figure 2(b). The inward movement of the wall at the base of the stem is responsible for the lateral pressures exceeding the Rankine active values in steep cuts.

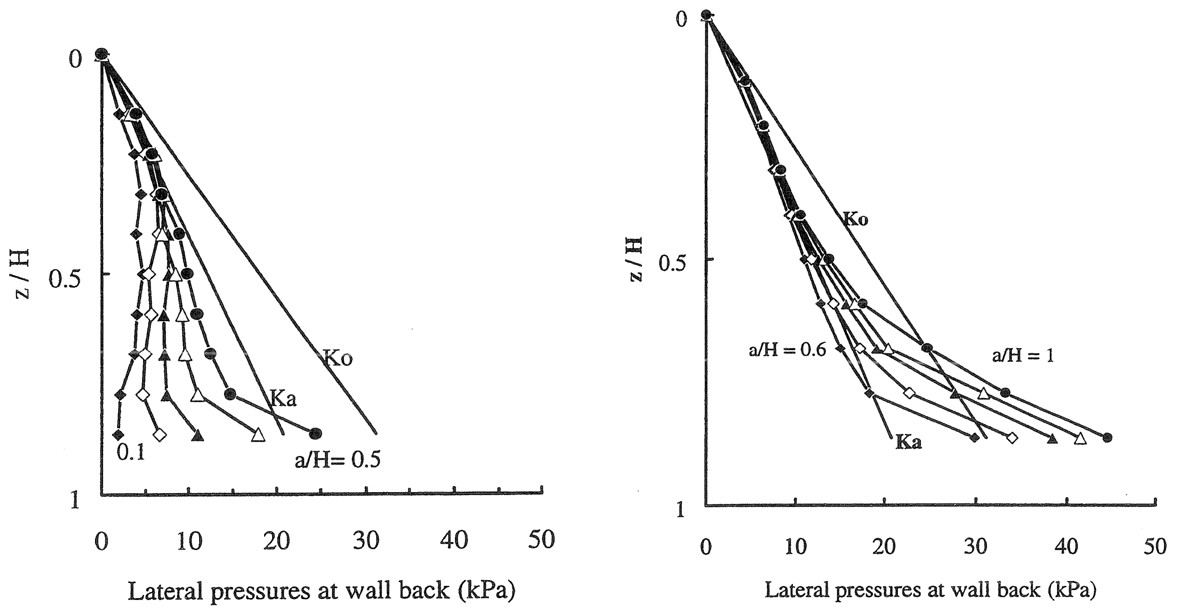
The results in Figure 2 show that the lateral pressure distribution, and accordingly the lateral thrust, P, increases as the size of the backfill increases for all types of clay. To account for the variation of lateral thrust acting on the wall from the classical Rankine value,, a correction factor, β, has been used to express this variation:

$$P = \beta P_a \qquad (1)$$

where P_a is the Rankine active thrust along the back of the wall, for a homogeneous sand backfill.

Figure 3 shows the variation of the correction factor, β, with the size of the triangular backfill. The increase of the lateral thrust with the ratio (a/H) agree with the solutions obtained by the procedure proposed by Huntington (1957).

However, the results do not agree with the design charts presented by Bang and Tucker (1990) for an interposed backfill wedge. This is possibly because the design charts are strictly applicable to an excavation surface with a "negative slope" where the slope is towards the retaining wall, while the results shown in Figure 3 are for an excavation surface with a corresponding "positive slope".



(a) (b)

Figure 2. Lateral pressure profiles at the wall back for stiff clay (a) a/H = 0.1-0.5, and (b) a/H= 0.6-1.0

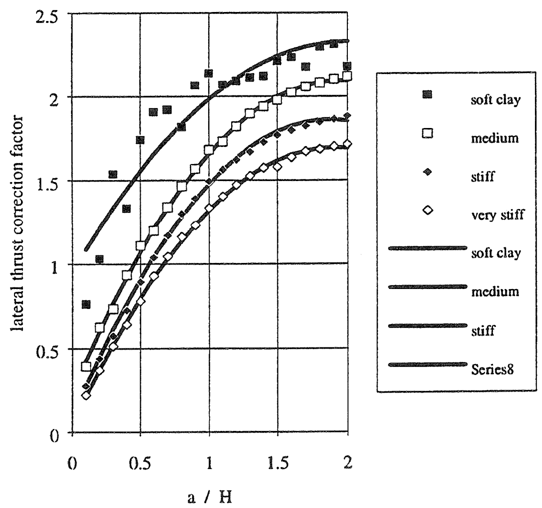


Figure 3. Correction factor for triangular backfill behind retaining wall supporting a cohesive soil

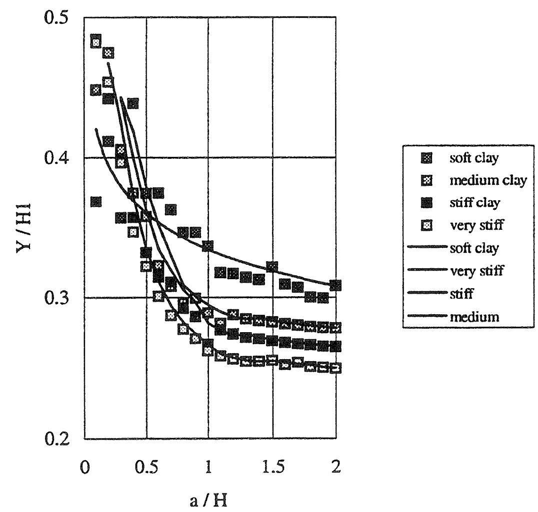


Figure 4. Location of lateral thrust (Y/H1) for triangular backfill

The line of action of the lateral thrust, measured from the top of the base, Y, was determined and normalised with respect to the height of the stem (H1) and the results are shown in Figure 4 for the triangular backfill. The distance of the line of action, (Y/H1), of the lateral thrust decreases as the ratio (a/H) increases, and is approximately equal to the classical value of (H1/3) for (a/H) between 0.6 and 1.0. For steep cuts (a/H<0.5) the lateral thrust is close to the mid height of the stem. For gentle cuts (a/H > 0.5), the lateral thrust is lower than the Rankine value, most likely due to the development of passive conditions around the base of the stem.

Figures 5 and 6 show the effect of a rectangular backfill. The variations of the correction to lateral thrust are less than those obtained for triangular backfills. Indeed, for soft clay, the correction factor, β, is between 0.75 and 1.25 for (a/H) between 0.1 and 0.5. Figure 6 shows that the assumption that the line of action of the lateral thrust is located close to (H1/3) can be used only for medium, stiff, and very stiff clays. In soft clay, the instability in the natural deposit causes large values of the lateral pressures within the upper half of the wall, which cause the lateral thrust to shift above the classical solution of Y = (H1/3).

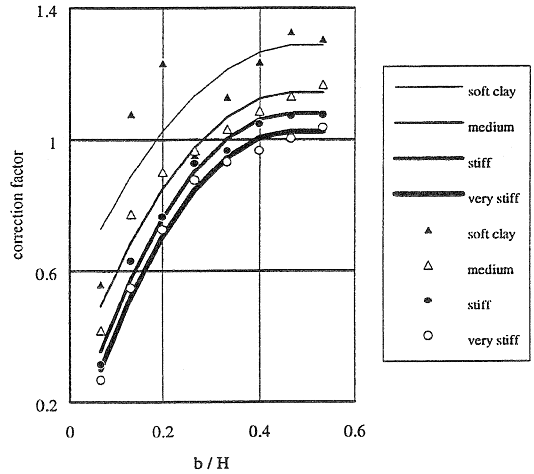


Figure 5. Correction factor, β, for rectangular backfill

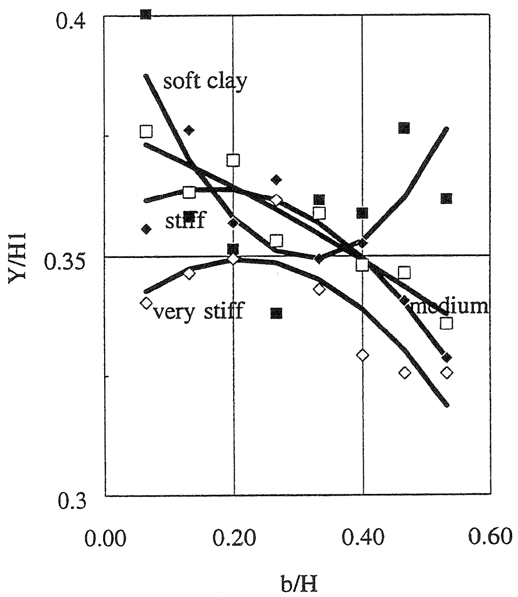


Figure 6. Location of the line of action of lateral thrust for rectangular backfill

Figures 7 and 8 show the results obtained for a trapezoidal backfill. Figure 7 demonstrates that the maximum variation of β is of the order or 30%, compared to variations of 100% obtained for triangular backfills. Figure 8 shows that the assumption that the line of action of the lateral thrust is located close to (H1/3) is justified except for soft clays. In soft clay, as is the case for rectangular backfills, the overall instability in the natural deposit causes large values of the lateral pressures within the upper half of the wall, which leads to a shift of the lateral thrust towards the middle.

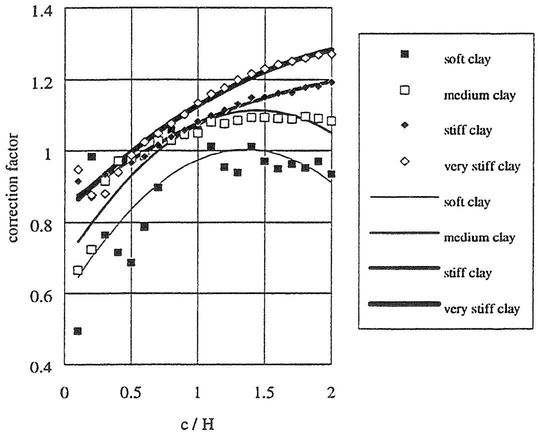


Figure 7. Correction factor, β, for trapezoidal backfill (at virtual wall back)

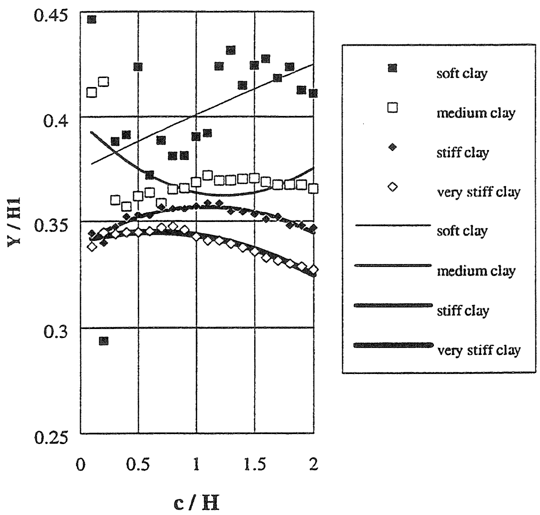


Figure 8. Location of the line of action of the lateral thrust for trapezoidal backfill (at virtual wall back)

Thus, in the case of rectangular and trapezoidal backfills, the lateral pressure distribution is trapezoidal rather than triangular. It appears that the pressure distributions in soft clay recommended by Tschebotarioff (1973), although developed for deep excavations, may be applicable even for shallow excavations.

5. CONCLUSIONS

It has been demonstrated that classical earth pressure theories are not always suitable for determining the lateral thrust in the case of limited backfills. Generally, the lateral thrust increases as the backfill size increases for the backfill geometries considered. In soft clays, the lateral pressure distribution is greatly influenced by the deformations in the natural deposit due to the weight of the backfill.

The size of the base of the retaining wall controls the relative magnitudes of settlement and lateral movements, especially for rectangular and triangular backfill geometries.

ACKNOWLEDGMENTS

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