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# The influence of the shape of the lateral soil-wall boundary on the performance of geosynthetic reinforced soil structures

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ABSTRACT: Laboratory testing has recently been undertaken on vertical and steep-sided walls wherein the shape of the lateral boundary was a variable. In this paper, the basic earth pressure concepts are described and their application to non-planar lateral boundaries is presented. The laboratory test programme undertaken is described and the test data presented. These show that non-planar lateral boundaries allow designers the possibility of controlling the lateral earth pressures in magnitude and distribution, as well controlling the toe bearing pressures. Thus they are shown to have the possibility of providing both technical and aesthetic benefits not available within current design processes.

## 1 INTRODUCTION

Historically, lateral earth pressure theories for vertical or steep-sided walls have been based on equilibrium conditions within a fill with no lateral boundary deformation, (at-rest conditions), or limit equilibrium conditions for either lateral expansion (active conditions) or lateral contraction (passive conditions). The lateral boundary was always taken to be planar, either vertical or inclined. Occasionally, stepped or terraced boundaries were considered.

The introduction of Geosynthetic Reinforced Soil has not change this convention. Therefore, as a result of the continuation of the use of essentially planar lateral boundaries, the lateral earth pressures to be resisted by Geosynthetic Reinforced Soil Structures [GRSSs], generally increase in proportion to the height of the wall. This can result in a complicated reinforcement layout, with the spacings, lengths and types of reinforcement varying with depth. In addition, the base bearing pressures near the toe of the GRSS increase in similar proportion.

These features have proven to represent severe limitations on the height of GRSSs that can be reinforced using specific types of geosynthetics and on the height and facing angle of structures that can be built over poor quality sub-soil types.

## 2 BASIC EARTH PRESSURE CONCEPTS

Conventional earth pressure theories show that the magnitude and distribution of lateral earth pressures on a lateral soil-wall boundary are dependent upon many factors, including:

- the type of soil employed as the reinforced fill,
- the density of the fill,
- the magnitude of the soil-wall friction and
- the nature and magnitude of the soil-wall boundary movements.

Further, it is widely known that as the facing angle of a GRSS reduces so the lateral earth pressure reduces. Indeed, the earth pressures reduce to zero once the facing angle is less or equal to the operational angle of friction of the soil.

By selecting the soil type, the construction process and the nature of the lateral soil-wall boundary, it would thus appear possible to control the magnitude and distribution of lateral earth pressures developed by a GRSS.

To date the soil-wall boundary has been considered to be a fixed parameter, either vertical, inclined or stepped, Fig.1.

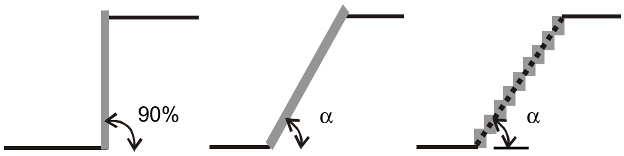
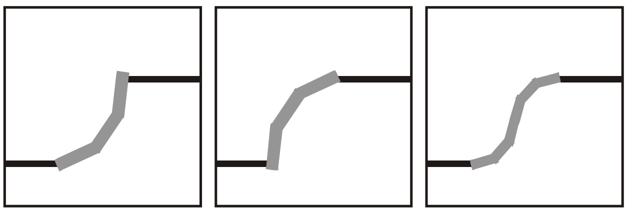



Figure 1 Variation of facing slope angle

However, if the slope angle of the facing [ ] is varied between 90º and ', the earth pressure distribution will not conform to conventional patterns, either in magnitude or distribution. Indeed by varying the angle of the lateral soil-wall boundary, both the levels and distribution of the earth pressures can be controlled. Possible shapes of the soil-wall boundary are shown in Figure 2.



(a) Concave (b) Convex (c) Compound

Figure 2 Possible variation of the lateral soil-wall boundary (multi-linear or curved facings, either smooth or stepped)

This approach may be readily employed in GRSSs by utilising sectional or wrap-around facings.

## 3 TEST SETUP

A recently conducted test programme was aimed at the determination of the lateral and base pressures of non-planar lateral soil-wall boundaries. In this paper only the test data obtained for the at-rest conditions are presented, viz. test walls were rigid and fixed. The test apparatus used for this case consisted of a rigid frame of 0.50m height and 0.80m width, Plate 1. Load cells were fixed to one side of the frame and along the base, to measure the lateral and vertical pressures. The load cells used to measure the lateral thrust were 50mm in height and 70mm in width, the base load cells were 80mm in length and 70mm in width and all were covered in a layer of PTFE to reduce surface friction. Calibration of both sets of load cells showed them to be accurate to ±0.05N.

To simulate a granular fill, the frame was sequentially filled with an equal mixture of brass rods of 2, 3 and 4mm diameters and 70.5mm length. Prior to filling the frame, the rods were immersed in a weak phosphoric acid for at least 24 hours to remove any oxidized patina. The compacted fill had a density [ρ] of 7.08Mg/m$^3$ and hence a unit weight of 69.5kN/m$^3$. The angle of internal friction was determined using shear-box tests and shown to be 21°. The coefficient of earth pressure for the At-rest conditions[$K_0$] was calculated as:

$$K_0 = 1 - \sin\phi = 0.642 \qquad (1)$$

This value was used to check the test data obtained from the apparatus using the rigid vertical wall. The correlation between the calculated and measured At-rest lateral earth pressures are shown in Figure 3. The correlation between the measured base pressure and the calculated vertical overburden pressure is shown in Figure 4. The deviation of the measured values from the calculated values in each case is due to the residual friction on the PTFE coated sides and base.

The minimum number of tests to be conducted to achieve a 95% confidence limit was determined and shown to be four tests. Hence, all other tests were conducted at least four times.

Various other planar and non-planar lateral boundary shapes were constructed by fixing lightweight tubes of different lengths between the lateral load cells and the PTFE coated facing units. The brass rods were then placed against them. Using this method, lateral boundary shapes were formed as linear slopes with inclinations varying from 90° to 45° and curves with L = H$^2$, 0.5H$^2$, 0.33H$^2$, H$^3$, 0.5H$^3$, 0.33H$^3$, (where L is the lateral dimension and H is the vertical dimension measuring from the top of the wall).

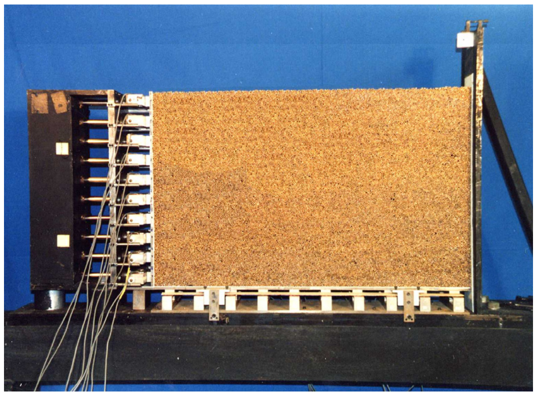


Plate 1 Test set-up and test apparatus (vertical wall)

## 3.1 *Planar Lateral Soil-Wall Boundary Conditions*

The measured lateral pressure distributions for the planar lateral boundaries at different slope angles exhibited a progressive reduction in lateral pressures with reducing inclination, as shown in Figure 5. They also exhibited a significant reduction in base bearing pressures near the toe of the wall, as shown in Figure 6. Thus the measured benefit of reducing the inclination of planar lateral boundaries was two-fold and in line with existing knowledge.

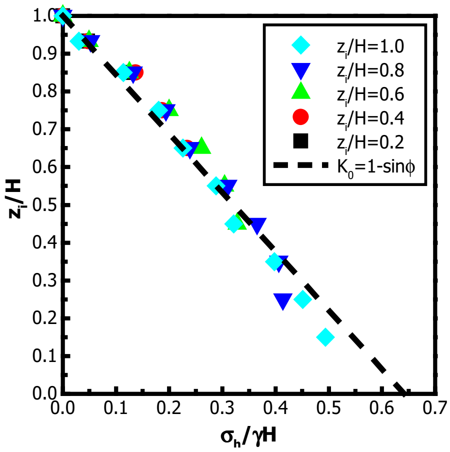



Figure 3 Normalised at-rest lateral earth pressures (90° Wall) [$z_i$ is the construction height]

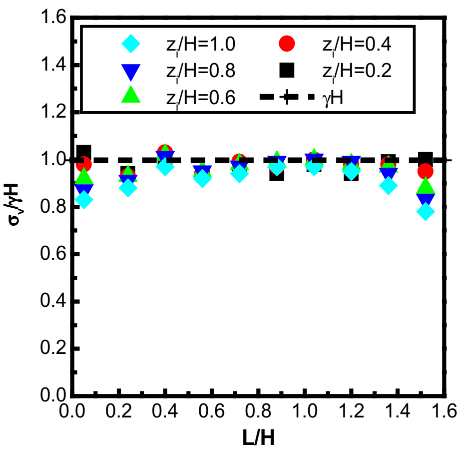



Figure 4 Normalised base pressures (90° Wall)

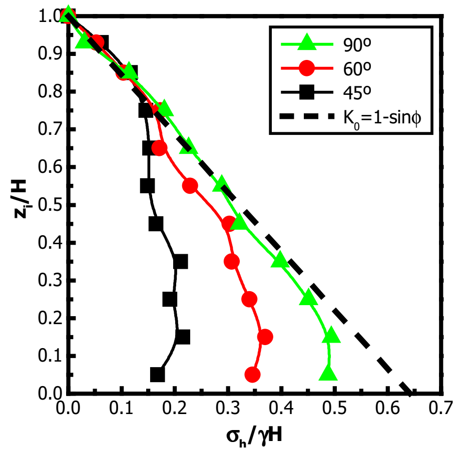



Figure 5 Reduction in lateral pressures with reducing inclination (Planar Soil-Wall Boundary) [$z_i$ is the construction height]

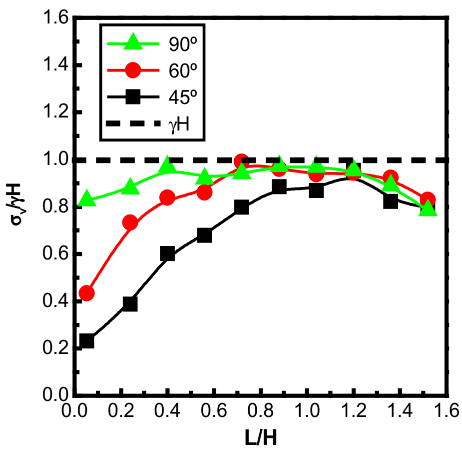



Figure 6 Reduction in base bearing pressures with reducing inclination (Planar Soil-Wall Boundary)

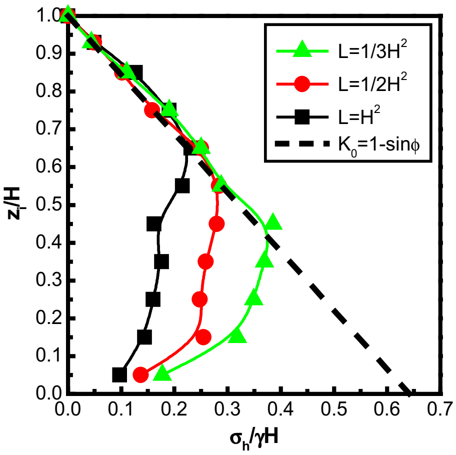



Figure 7 Reduction in lateral pressures (L=cH² curved Soil-Wall Boundaries) [$z_i$ is the construction height]

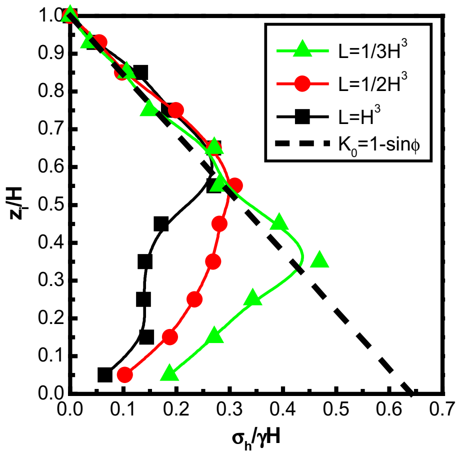



Figure 9 Reduction in lateral pressures (L=cH³ curved Soil-Wall Boundaries) [$z_i$ is the construction height]

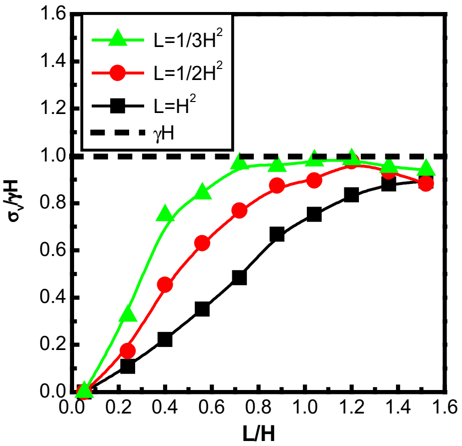



Figure 8 Reduction in base bearing pressures (L=cH² curved Soil-Wall Boundaries)

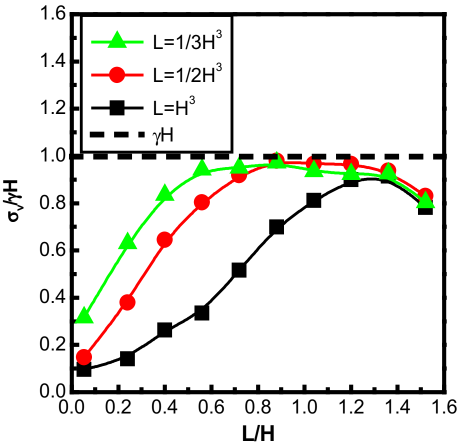



Figure 10 Reduction in base bearing pressures (L=cH³ curved Soil-Wall Boundaries)

### 3.2 *Non-planar Lateral Soil-Wall Boundary Conditions*

The measured lateral pressure conditions exhibited by different curved boundaries are shown in Figures 7 and 9. The base bearing pressures for these curved boundaries are shown in Figures 8 and 10. It can be seen that curved boundaries provide both the possibility of reduced lateral pressures and of reduced base pressure near the toe compared to the vertical wall condition. Of particular note, is the case of the curve boundary $L = 0.33H^2$, shown in Plate 2. This lateral boundary condition provides a relatively uniform pressure distribution with depth behind the wall and a significant reduction in the base bearing pressure near the toe, Figures 7 and 9 respectively.

## 4 OPTIMUM SHAPE OF THE LATERAL SOIL BOUNDARY

The method of constructing GRSSs is to place successive layers of compacted fill and Geosynthetics, with the latter connected to facing units or formed into a wrap-around facing. For construction simplicity, the thickness of the compacted fill layers should be kept the same and only one type Geosynthetic, or at the most two, used over the height of the GRSS. To do this, the pressures to be resisted at the lateral boundary require to be as uniform as possible, Figure 11. This will have the effect of ensuring that the loads carried by the various layers of Geosynthetic reinforcement are very similar over the full height of the GRSS. As a result, the lateral boundary deformations will be very uniform. On the basis of the experimental work described above, it will also have the advantage of reducing the base bearing pressures near the toe of the structure, Figure 12.

Where surcharges exist on the top of the GRSSs, then the shape of the boundary at the top of the structure may have to be modified to rapidly reduce lateral pressures, as shown in Figure 13.

A possible additional advantage is that for GRSSs subject to shock or earthquake loading, non-planar lateral soil-wall boundaries are likely to provide much more resistance than vertical or steep planar boundary conditions due to the more uniform lateral pressure distribution and reduced toe bearing pressures.

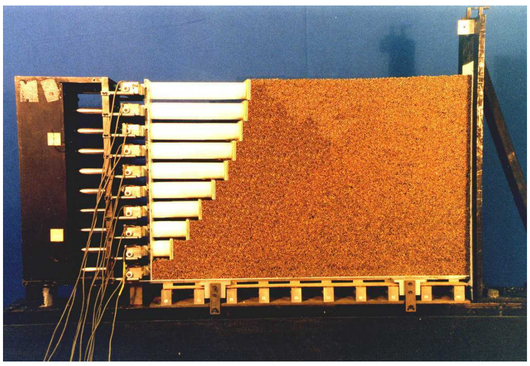


Plate 2 Curved Soil-Wall Boundary ($L = 0.33H^2$)

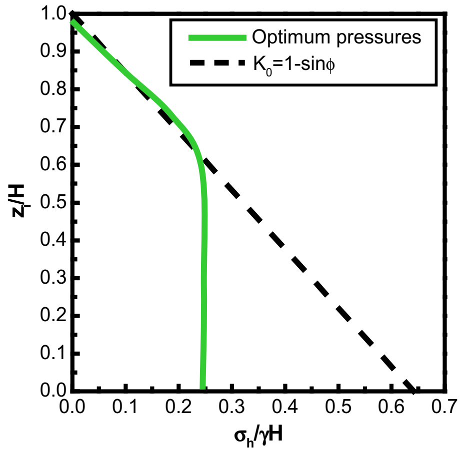



Figure 11 Optimum shape, constant lateral earth pressures [$z_i$ is the construction height]

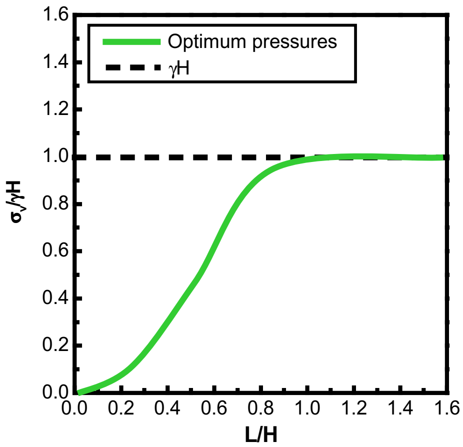



Figure 12 Optimum shape, low bearing pressures at toe of slope

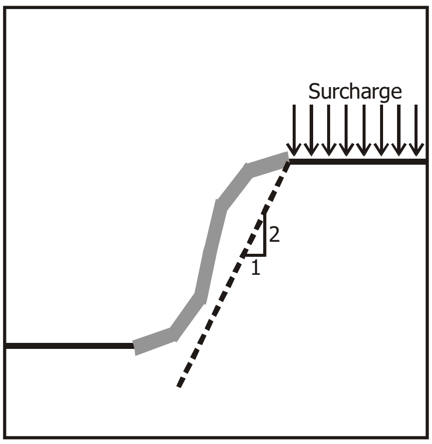



Figure 13 Modification of the Soil-Wall Boundary to reduce effects from surcharges

## 5 DISCUSSION

Leonards (1962) has shown that it is possible to determine the pressure distribution on a curved soil-wall boundary, e.g. a section of a deformed sheet pile wall or braced cuts. On the basis of field measurements Terzaghi and Peck (1948) and Tschebotarioff (1951) suggested that trapezoidal pressure distributions may be used as approximations in these cases. However, these simplified assumptions have not been widely employed in the design of retaining structures and do not in any case deal with the general condition of a curved soil-wall boundary.

In this paper, the influence of the shape of the lateral soil-wall boundary on the performance of GRSSs has been identified on the basis of small-scale laboratory testing. The tests were conducted on brass rod models with rigid lateral planar and non-planar boundaries. More extensive testing has been conducted on yielding lateral soil boundaries with similar shapes and these provided similar data.

The advantages shown to be accrued from the use of particular forms of non-planar lateral soil-wall boundaries were two-fold, viz. the possibility of more uniform lateral earth pressures with depth and reduced toe bearing pressures. To date increasing lateral earth pressures with depth and large toe bearing pressures associated with planar lateral soil-wall boundary conditions, have limited the application of GRSSs in practice. The possibility of controlling these factors by adopting non-planar lateral soil-wall boundaries appears to have considerable potential.

This technique is likely to allow the use of uniform spacings for reinforcements, which will allow increased standardisation of construction techniques and facing units. These are likely to reduce construction costs.

Analytical techniques are being developed which deal with this situation. These indicate that it is possible to determine the shape of multi-linear or curved lateral boundaries which will allow Designers to establish the "Optimum Shape" of the lateral boundaries. This Optimum Shape is taken to mean the shape that develops a constant (or pre-determined) lateral earth pressure with depth and / or a particular limiting toe bearing pressure.

Lastly, the ability of Designers to produce non-planar lateral soil-wall boundaries will have many aesthetic advantages.

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