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The use of a compressible boundary layer in reinforced soil structures

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ABSTRACT: The application of a compressible material at the back of reinforced soil retaining structures can reduce the lateral earth pressures of the backfill below the active conditions during the construction stage and minimise the post construction movement. This paper presents the full instrumentation, measurements and results of six large scale unreinforced and reinforced retaining structures with different boundary conditions and their practical implication.

1 INTRODUCTION

The reduction of lateral earth pressures in retaining structures can be achieved by allowing lateral deformation of the boundary, i.e., imposing a flexible or compressible boundary, rotating or translating a rigid boundary. Recent research carried out on the application of a compressible boundary for reinforced retaining structures has shown that a pressure below the active value can be achieved with minimum post construction movement, Andrawes et al (1990). Preliminary studies of numerical modelling using finite element analysis, Hovarth (1991), also indicated a consistent trend of earth pressure reduction by imposing compressible boundary for both reinforced and unreinforced retaining structures.

In addition, research carried out at the University of Strathclyde also indicates that the compressibility of the compressible material used is critical and the choice of adequate stiffness for the material is important to ensure the effectiveness of the technique. A composite compressible polystyrene mattress has been developed. This was used in six large scale retaining structures constructed at the Transport and Road Research Laboratory (TRRL), Crowthorne, U.K. to investigate the effect of boundary compressibility.

2 EXPERIMENTAL SET UP AND MATERIALS USED

2.1 Walls

The experimental retaining structures consisted of three types of facings, steel walls, a concrete wall and two timber walls. The configurations of the walls were as follow:

Steel Wall 1: unreinforced backfill with rigid boundary.
Steel Wall 2: reinforced backfill with rigid boundary.
Steel Wall 3: reinforced backfill with compressible boundary.

The walls were held in position during backfilling using a bracing system. After construction the walls were allowed to rotate about their tops away from the soil using a jacking system. This allowed the effect of rotation to be studied.

Concrete Wall: reinforced backfill with compressible boundary.

This wall was constructed using full height concrete panels of 0.5m thickness supported by buttresses to ensure rigidity. The results were used to provide reference for comparison with other walls.

Timber Walls 1 & 2: reinforced backfill with compressible boundary.

One with three full height vertical panels and one with three horizontal incremental panels. Each panel was 2.1m long and 0.7m wide. The timber walls were propped during construction. At the end of construction, the reinforcements were then locked tightly onto the wall panels and the props removed. The two construction methods were used to provide comparison of the effect of the construction procedure on the behaviour of the walls.

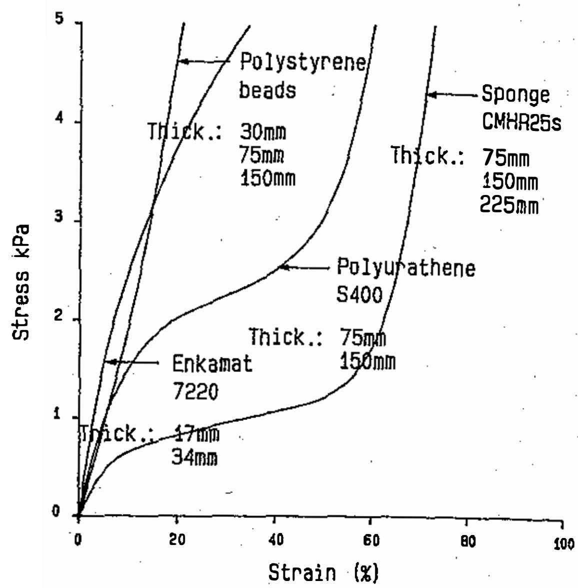

Fig 1 Compressibility of some polymeric materials.

2.2 Reinforcement

Three layers of Tensar SR80 geogrids, at vertical spacing of 0.7m, were used to reinforce the backfill. The reinforcements were not attached to the facing units during construction or after construction in all walls, except in the timber walls as discussed previously.

2.3 Compressible Material

Four polymeric materials, polyurathene S400 sponge, CMHR25s synthetic sponge, Enkamat 7220 and polystyrene beads were investigated for their compressibility. Samples of different thickness were subjected to compression tests under both confined and unconfined conditions. The results showed that the stress strain relationship is not affected by confinement or sample thickness. Typical results are shown in Fig.1. The sponge and polyurathene samples showed non-linear viscoelastic stress-strain behaviour under the range of compression stresses considered, however, the Enkamat and polystyrene beads showed non-linear elastic compressibility behaviour.

The observed compressibility behaviour of the sponge materials (S400 & CMHR25s) was due to the collapse of the cavities in the sponge at a certain stress range. This phenomena may cause serviceability problems for the retaining structures, especially when the cavities of the sponge are not fully collapsed after the end of the construction. Both the Enkamat 7220 and the polystyrene beads showed adequate stiffness characteristics, i.e., sufficient deformation under the applied earth pressures so that active conditions can be generated. For practical reasons, mattresses were fabricated using a geotextile filled with polystyrene beads to use as a compressible layer in the experiments. The mattress also can serve as a drainage layer at the back of the wall.

2.4 Backfill

The backfill material was a uniformly graded sand from Theale (Berkshire). The sand was compacted in 0.15m to 0.20m layers with two passes of a vibrating plate. The edge of the vibrator was 0.1m away from the facings to ensure that the compressible layer was not over compressed by the compaction plate. The average moisture content and bulk density were 9.4% and 1.83Mg/m^3 respectively. Triaxial tests on the Theale sand indicated that its internal angel of friction was 47°.

3 INSTRUMENTATION

Vertical and lateral earth pressures were measured using pneumatic pressure cells. Tensile loads and strains along the geogrids were monitored using specially designed load cells and strain gauges. Lateral deformation of the experimental walls and the polystyrene mattresses were recorded using dial gauges and Bison gauges respectively, while ambient temperature was measured using thermocouples.

4 RESULTS AND DISCUSSIONS

4.1 Lateral earth pressures (LEP)

For the steel Wall 1, high lock-in lateral stresses dominated the top half the fill as can be observed in Fig.2(a). These lock-in stresses were induced by compaction. Reduction in these stresses occurred when a small rotation about the top of the wall was applied. The magnitude of the reduction depended upon the amount of rotation applied. The non-linear distribution of the lateral earth pressure indicates soil arching, Fang and Ishibashi (1986). The same observations were also obtained from the experimental steel Wall 2 with more reduction in the LEP after wall rotation due to the presence of the reinforcements, as shown in Fig 2(b). However, a significant reduction in the LEP (below the

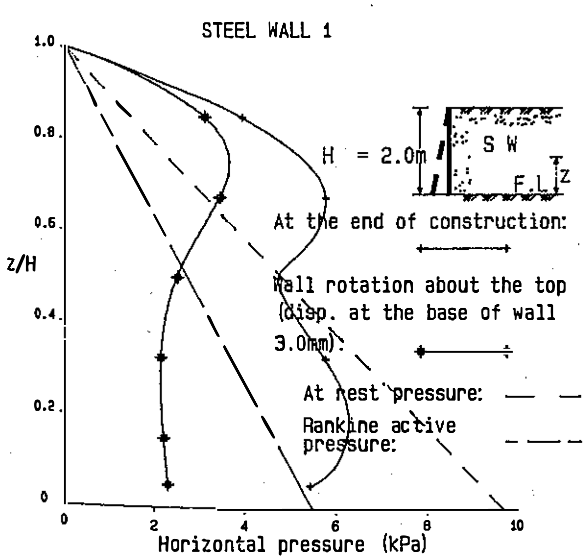

Fig 2a Lateral earth pressure distribution.

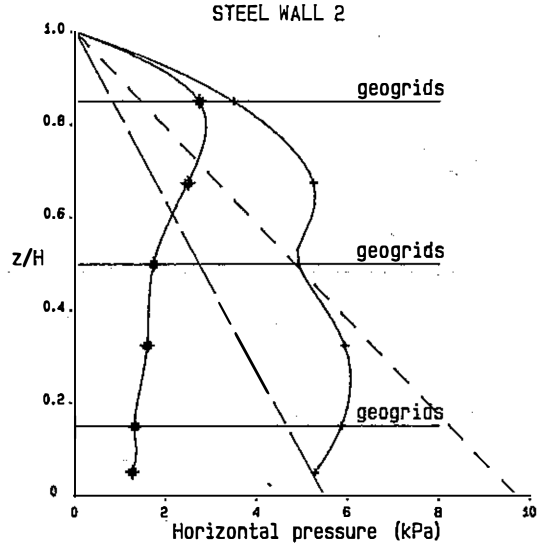

Fig 2b Lateral earth pressure distribution.

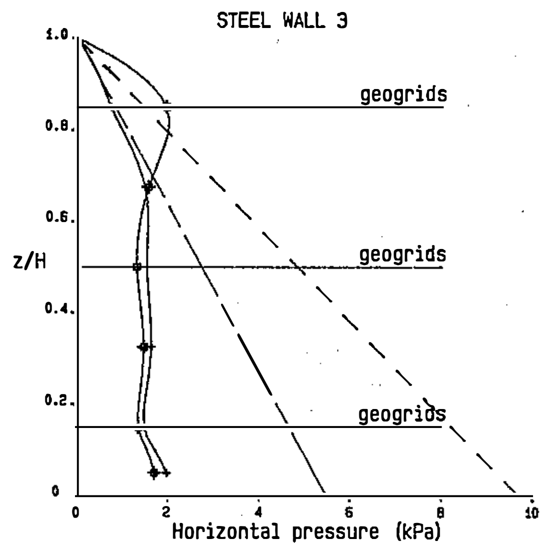

Fig 2c Lateral earth pressure distribution.

Rankine active conditions) was observed in the steel Wall 3 (compressible boundary and reinforced backfill) at the end of construction. The rotation of the wall has only a slight effect on the distribution of the LEP, as shown in Fig.2(c), except at the top part of the wall where the pressure increased. This may be due to the inward movement of the compressible layer at the top, which in turn caused passive pressures to develop.

It has been observed that the LEP distributions at the back of the concrete wall and the timber panel walls were similar to that of steel wall 3 at the end of construction. This reinforces the repeatibility of the test results. In addition, the LEP distributions for both the full panel and incremental panel timber walls before and after the removal of the props were similar. This implies that with the inclusion of a compressible layer, the influence of compaction and construction method on the LEP distribution can be insignificant.

4.2 Vertical earth pressures (VEP)

A comparison between the VEP distributions at the foundation level of the steel Walls 1, 2 and 3 before and after rotation is demonstrated in Fig.3.

These VEP distributions were uniform with a value close to the overburden pressure, except near the facing units where the VEP was lower than the overburden pressure. This observation is attributed to the friction developed between the wall face and the backfill. By allowing the boundary deformation to take place during construction, higher boundary frictional forces were mobilised. This caused a reduction in the VEP in the vicinity of the facings as seen in Fig.3(c).

The results suggest that by allowing dcformation cithcr by rotation or by application of compressible layer at the back of the walls, the VEP immediately behind the walls reduces.

4.3 Load/strain along the geogrids

Tensile strains (loads) were developed along the reinforcement due to compaction in all cases. By allowing boundary deformation, either by using a compressible boundary (Fig.4(b)) or rotaionof a rigid boundary (Fig.4(a)), the strains (loads) increased. However, when using a compressible boundary, these deformations occur during construction. The same behaviour was observed for concrete and timber walls (at the end of construction).

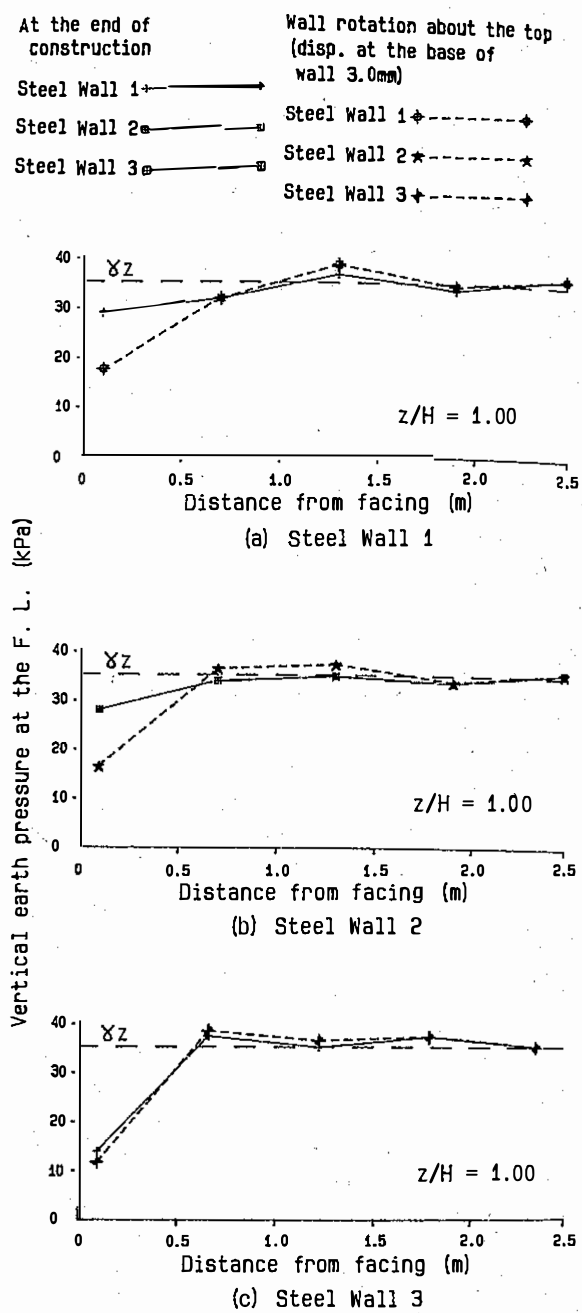

Fig 3 Vertical earth pressure distribution.

For the two timber walls, the reinforcements were tightened to the facing before the removal of the props. This caused the transfer the peak load/strain position to the front of the walls, as shown in Fig.4 c. No significant difference between these distributions for the full panel or incremental panel wall was observed.

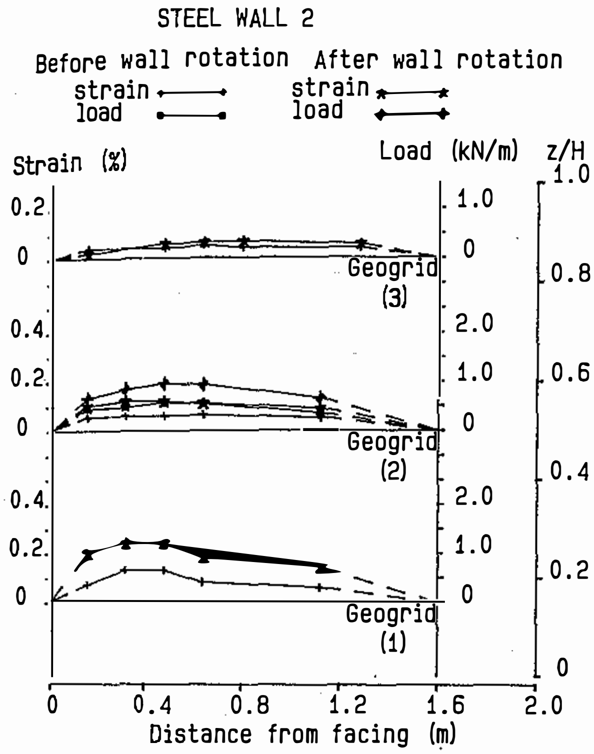

Fig 4a Load/strain distribution along the geogrids

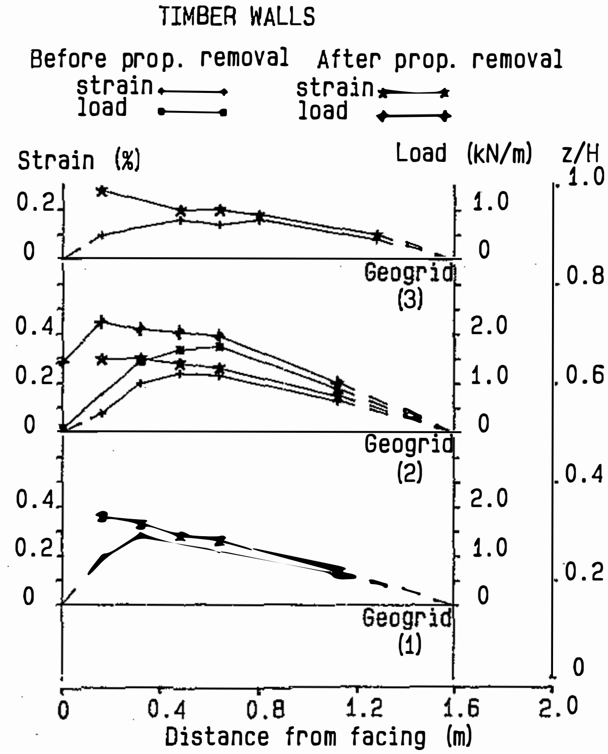

Fig 4c Load/strain distribution along the geogrids

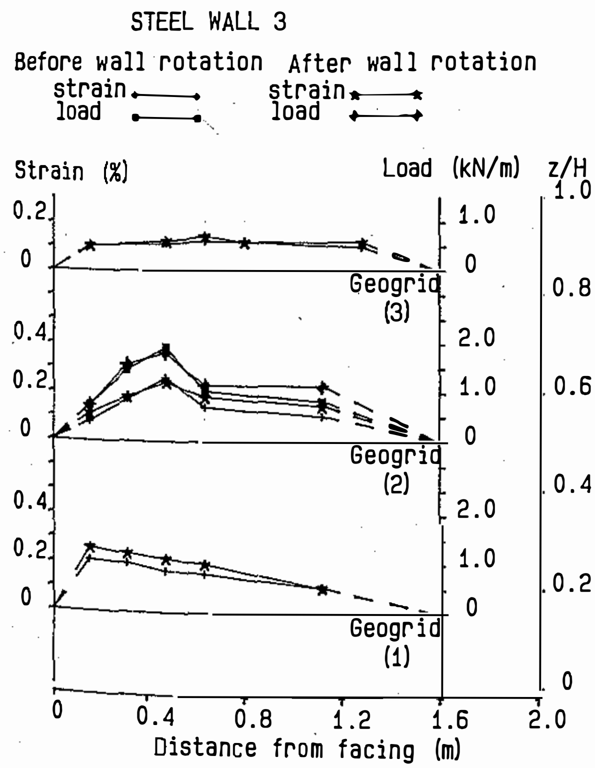

Fig 4b Load/strain distribution along the geogrids

5 CONCLUSIONS

The results of the experiments indicate that the application of a compressible layer can reduce the induced pressures caused by compaction. In addition, the choice of construction technique, i.e., full panel or incremantal panel, has little or no effect on the behaviour of reinforced soil wall.

The Polystyrene mattress developed has proved to be innovative for the reasons of low cost and ease and flexibility of construction. In addition it also may be used to provide drainage, thermal and sound isolation and vibration absorbtion of dynamic or live loads.

Using a compressible boundary allows the shear strength of the soil to be mobilised during construction thus minimising the lateral earth pressures. Figure 6 shows the relationship between the ratio K_{m}/K_{o} and the horizontal deformation expressed as a percentage of the wall height. It indicates that by imposing a compressible boundary, the lateral pressures

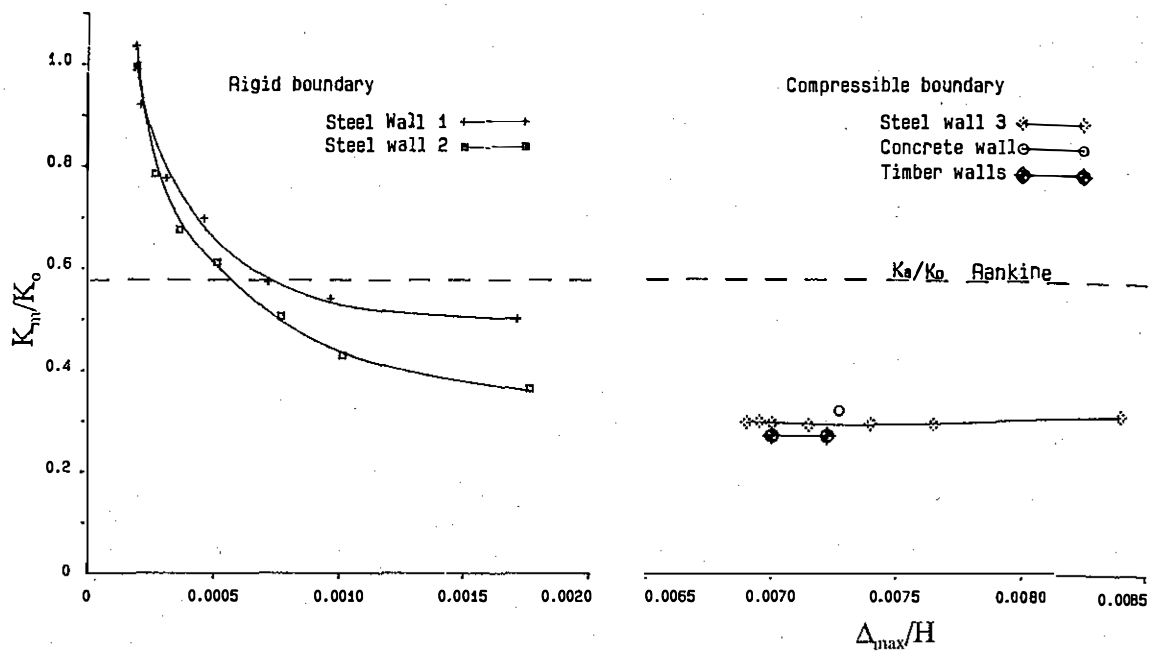

Fig 5 The change of K_m/K_o versus wall movement Δ_{max}/H

developed were well below the Rankine active condition. By identifying the required deformation to achieve this, it is possible to select a compressible material with a suitable stiffness and determine the minimum thickness required.

Attachment of the reinforcements to the facings in a free standing wall, transfers the peak strains and loads towards the connections. The tightening of the connections causes the peak strains and loads to be transferred to the joint as in the case of the timber walls. This may be undesirable since the joint is normally the weakest link in the system.

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