Geogrid Reinforced Soil Walls Subjected to Controlled Lateral Deformation

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ABSTRACT: The paper presents the results of fully instrumented three large scale free standing geogrid reinforced soil walls with different flexural rigidity and lateral stiffness of the facing. The measured behaviour of the walls was compared with the corresponding predicted behaviour obtained using a finite element simulation. The results indicate that the use of a compressible layer at the facing optimises the mobilisation of the soil strength and the strains in the geogrid, thus reducing the lateral pressure and improving the distribution of tensile strains along the reinforcements.

1 INTRODUCTION

The introduction of geogrids as reinforcements increased the cost-effectiveness and acceptance of reinforced soil retaining structures. This has been demonstrated by the large number of geogrid reinforced soil structures constructed throughout the world.

In order to achieve the minimum lateral pressure on the retaining structures it is necessary for the backfill to be allowed to expand laterally. In traditional gravity walls the lateral expansion of the backfill can be achieved by lateral movement of the wall. When reinforced soil walls are used, movement of the lateral boundary (soil/facing boundary) can occur either due to the low flexural rigidity or low lateral stiffness of the lateral boundary. The distinction between the flexural rigidity and lateral stiffness is that flexural rigidity relates to the ability of the facing to resist bending moment along its length whereas lateral stiffness relates to the ability of the facing to decrease in thickness under compressive loads.

A research program has been undertaken for several years at the University of Strathclyde to investigate the effect of lateral boundary movements on the behaviour of unreinforced and reinforced soil walls. Preliminary studies using laboratory models, (McGown et al, 1988 and Andrawes et al, 1990), showed that the resulting lateral earth pressures of the reinforced and unreinforced backfills were greatly influenced by the magnitude and mode of these movements. As part of this programme, experiments were conducted on 2.0m high geogrid reinforced soil walls. The lateral stiffness of the facing was decreased by placing a compressible layer between the backfill and rigid facing units. The flexural rigidity of the lateral boundary was changed by using full height panels or incremental panels construction. The experimental walls were fully instrumented and monitored over a period of six months after construction.

A numerical modelling for the experimental walls was carried out using the finite element method to predict the behaviour of the walls. The predicted behaviour of the walls was compared with the corresponding measured behaviour in order to assess the validity of the theoretical analysis. The finite element solution was extended to identify the optimum thickness of the compressible layer.

2 DETAILS OF THE EXPERIMENTAL WALLS

The experimental retaining structures consisted of three reinforced soil walls (W1, W2, and W3). The configurations of the walls were as follows:

W1: full height vertical panels with a rigid boundary.
W2: full height vertical panels with a compressible boundary.
W3: horizontal incremental panels with a compressible boundary.

2.1 Construction Materials

Each wall facing comprised three timber panels. Each panel was 2.1m long and 0.7m wide. The compressible layer was in the form of a 150mm thick mattress of polystyrene beads. The backfill material was a uniformly graded sand from Theale (Berkshire). The average moisture content and bulk density were 9.4% and 1.83Mg/m^3 respectively. Triaxial tests conducted under these conditions on the sand indicated that its internal angle friction was 47°. Three layers of Tensar SR80 geogrid were placed at heights 0.3m, 1.0m and 1.7m from the base (vertical spacing of 0.7m). The length and the width of each reinforcement layer were 1.6m and 2.1m respectively. Full details of the experimental set up is given by Saad (1993).

2.2 Measurements

The walls were fully instrumented and monitored during construction and over a period of six months after the end of construction. The measurements included:

(a) lateral and vertical earth pressures using pneumatic pressure cells,
(b) lateral deformation of the facing using dial gauges,
(c) deformation of the compressible layer using six pairs of Bison strain coils,
(d) tensile loads along the reinforcements using specially designed load cells distributed along the geogrid layers at selected positions,
(e) strains along the reinforcement using high elongation strain gauges bonded to the geogrid at the centres of selected bars,
(f) the ambient temperature using thermocouples placed at different locations within the backfill.

2.3 Construction process

The compressible layer was mounted firmly at the back of the panels. The backfill was placed and compacted in 0.15m to 0.20m layers with two passes of a vibrating plate. For the full height panel walls (W1 and W2), the panels were propped during the placement and compaction of the backfill. After the completion of construction, the reinforcements were gradually locked onto the panels by tightening the geogrid/facing connections while the loads on props were continuously monitored. The props were removed when the loads on the props reduced to zero and it was assumed that the loads were completely transferred to the reinforcements. For the incremental panel wall (W3), the same procedure was repeated for each panel separately.

3 NUMERICAL MODELLING

The finite element simulation was carried out using the CRISP geotechnical finite element program developed by the University of Cambridge (Britto and Gunn, 1990). The program has the provision of using elasto-plastic constitutive models and isoparametric elements with additional interface and bar elements to allow reinforced soil to be modelled. The finite element mesh used in the current study is illustrated in Fig. 1.

3.1 Modelling the construction materials

The soil was modelled using 6-noded triangular and 8-noded quadrilateral elements with Mohr-Coulomb failure criterion. The reinforcement layers were modelled using 3-noded bar elements which provide stiffness only in the axial direction. The timber panels and the compressible layer were modelled using 8-noded quadrilateral elements with elastic properties. The initial thickness of the compressible layer was 150mm which was altered in a later stage to obtain the optimum thickness of the compressible layer.

3.2 Modelling the interfaces

Interface elements were provided between the soil and the other construction materials (i.e., reinforcement, facing and compressible layer). No interface elements were provided between the facing and the compressible layer. However, interface elements were used to separate the panels of the incremental panel wall.

3.3 Modelling the construction process

The in-situ stresses developed in the backfill were simulated by placing the soil elements in layers. The Poisson's ratio was varied along the soil profile to allow the in-situ compaction stresses to be modelled. Hinged supports were applied beneath the foundation while roller supports were used at the left and right sides of the mesh to allow any vertical movements to occur. The supports of the panels were subsequently removed in a single step to model the simultaneous removal of props. For the incremental panel wall (W3), the construction process was modelled by supporting only the panel which was being constructed. Thus the movements of the lower panels were governed by the elongation of the reinforcements.

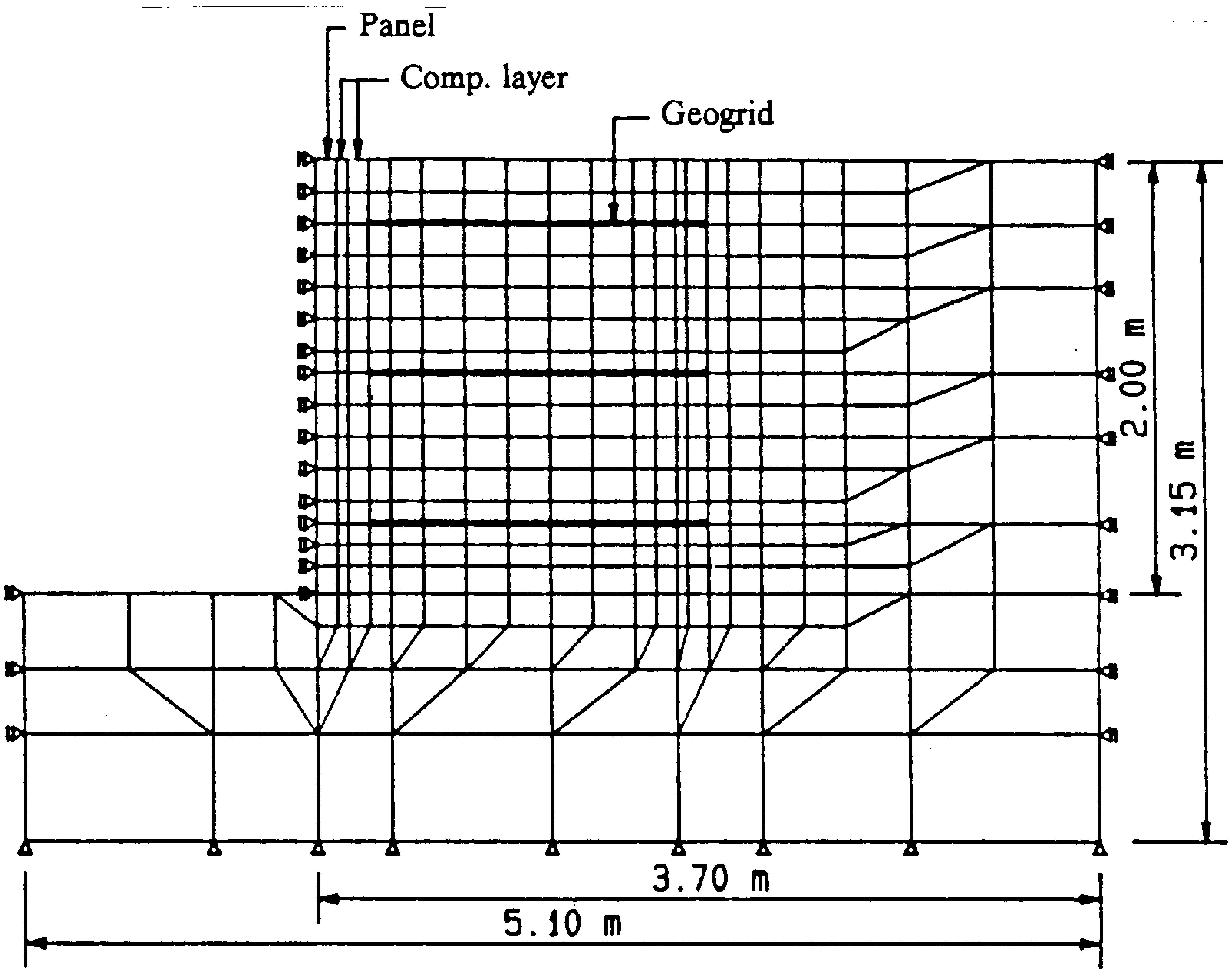


Fig.1 Finite element mesh

4 RESULTS AND DISCUSSIONS

4.1 Lateral deformation

The compression of the compressible layer developed progressively during the placement and compaction of the backfill. The maximum compression recorded for the compressible layer was about 15mm. For the walls with compressible layer (W2 and W3), the measured lateral deformations of panels indicated that the positions of the panels were slightly affected with time, with a maximum outward movement of the panels of about 0.5mm six months after removal of the props. The corresponding value for the panels with rigid lateral boundary (W1) was 3.5mm.

Similar behaviour was observed from the numerical modelling.

4.2 Lateral earth pressure

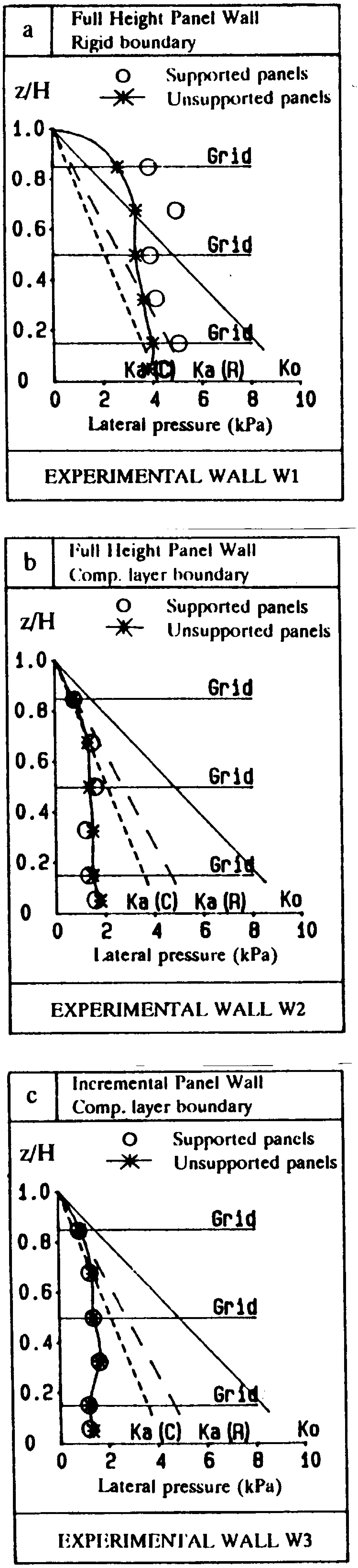
A comparison between the measured and predicted lateral earth pressure distributions for the three walls (W1, W2, and W3) before and after removing the supports is presented in Fig. 2.

For wall W1 (rigid lateral boundary), the deformation of the boundary during construction was insufficient to eliminate the compaction effect on the lateral pressure along the top half of the wall, where high 'locked-in' stresses dominated this part. The use of a compressible layer at the lateral boundary of the walls W2 and W3 eliminated the induced pressure caused by compaction and reduced the lateral pressure to below both Rankine and Coulomb active values. The progressive yielding of the lateral boundary during the construction allowed the tensile strains to occur in the backfill thus mobilising the shear strength of backfill and the tensile resistance of the reinforcements which resulted in a decease in the lateral earth pressure.

The lateral pressure distributions for both W2 and W3 before and after the removal of the props were similar. A point to note is that removing the props caused a significant reduction of the lateral pressure distribution for W1 which was relatively higher than the distributions for both W2 and W3.

A good agreement was observed between the experimental and predicted distributions.

The results of six simulations using different thickness for the compressible layer is shown in Figure 4. The Figure shows that there is a minimum thickness of the compressible layer above which no more reduction in the lateral earth pressure is possible.



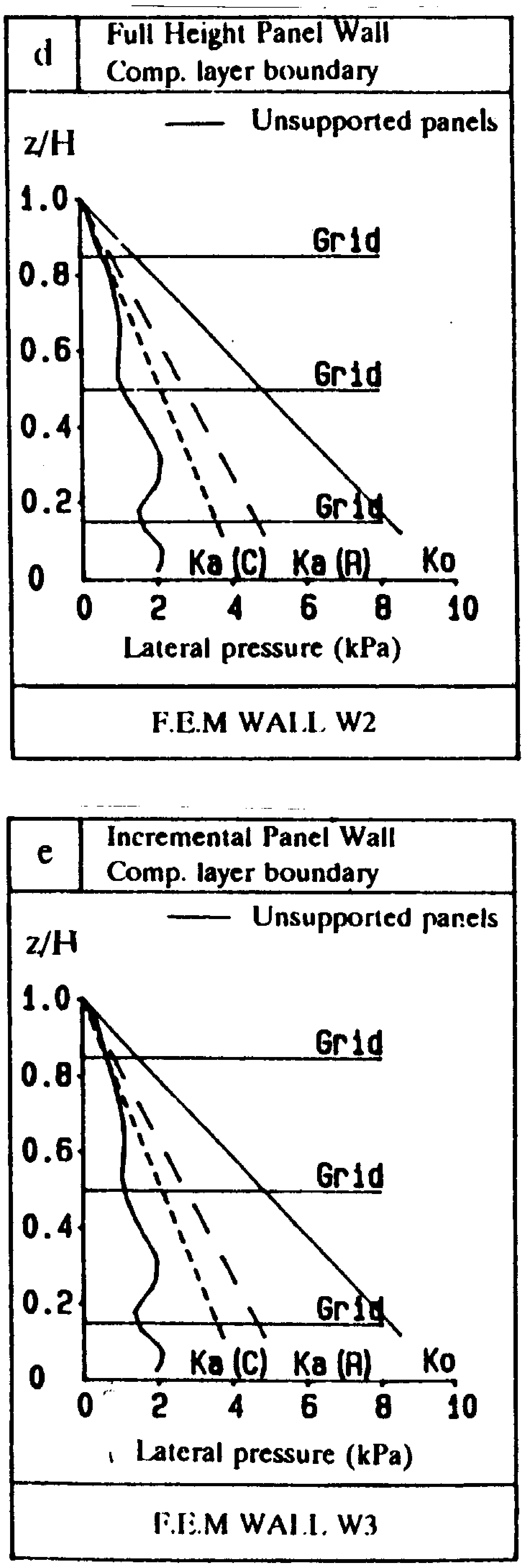
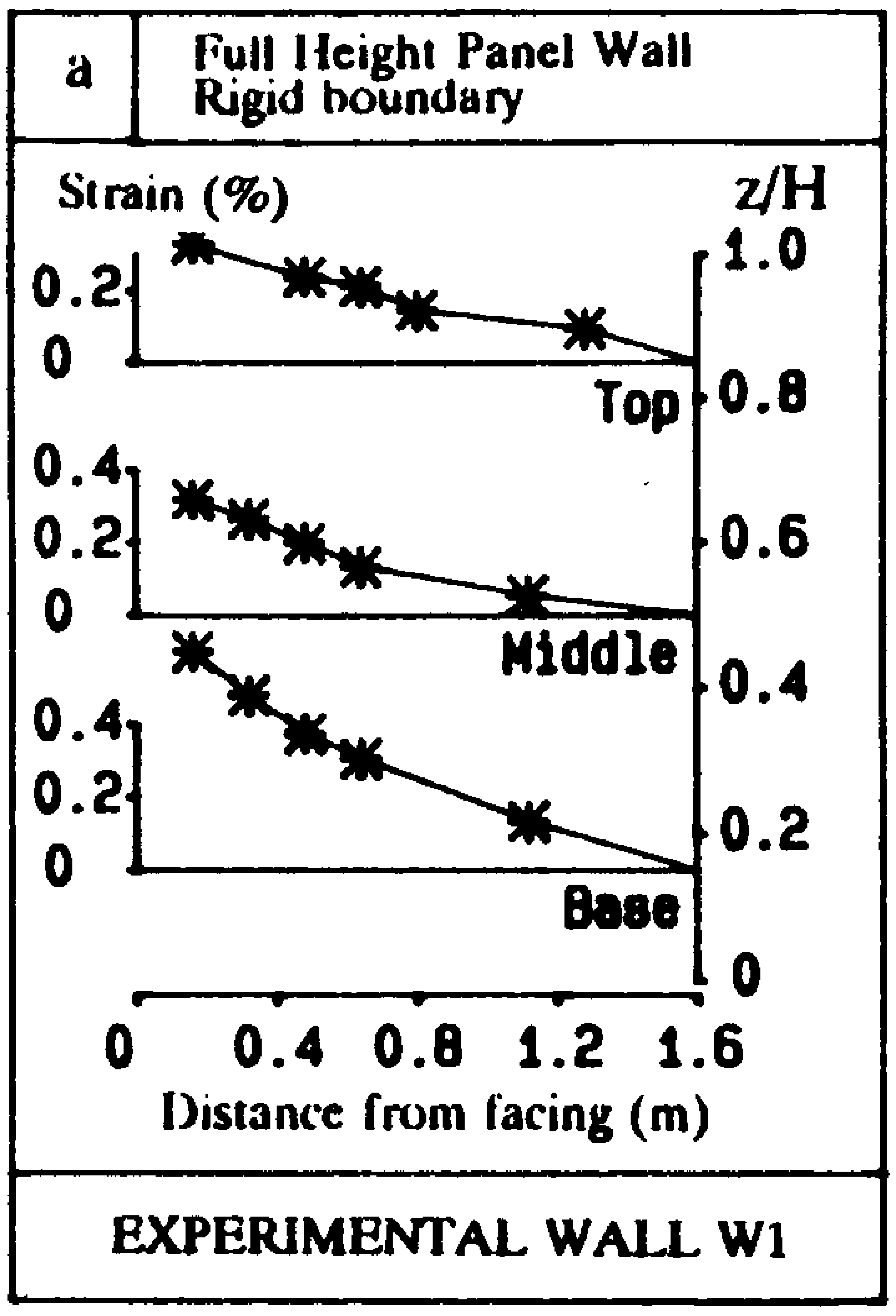


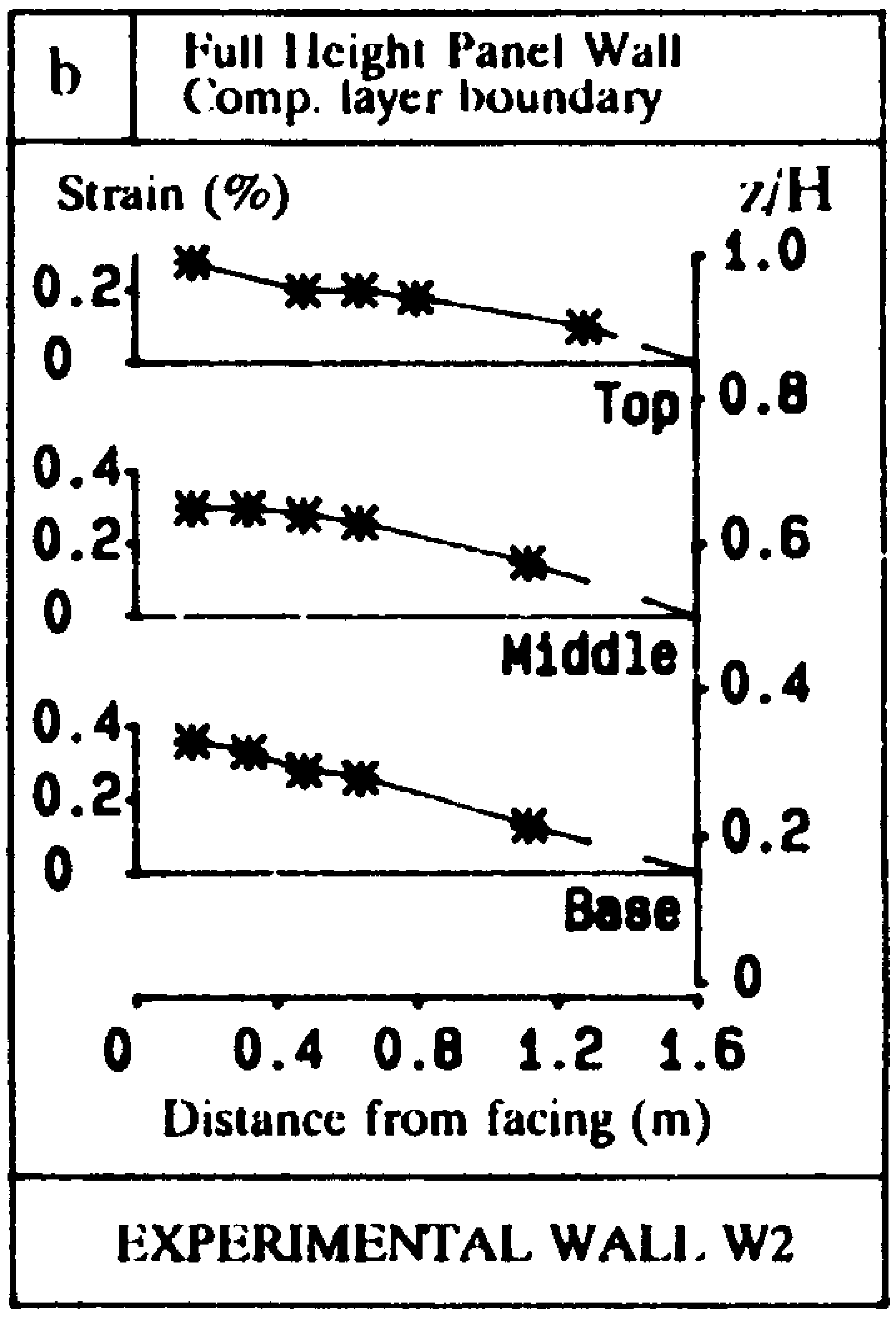
Fig.2 Lateral earth pressure distribution. (a), (b) and (c): Experimental results, (d) and (e): Finite element model.

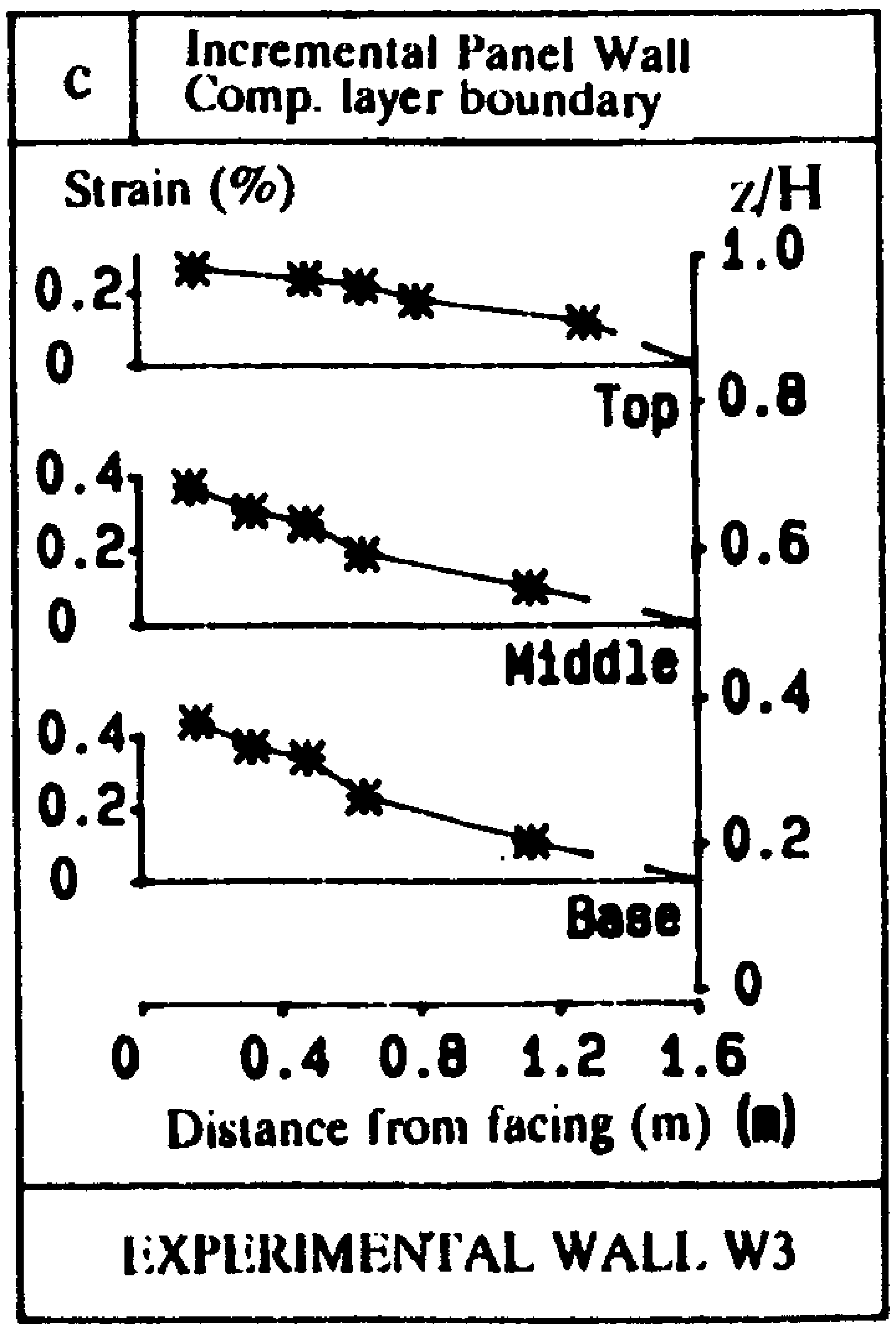
4.3 Strains along Reinforcement

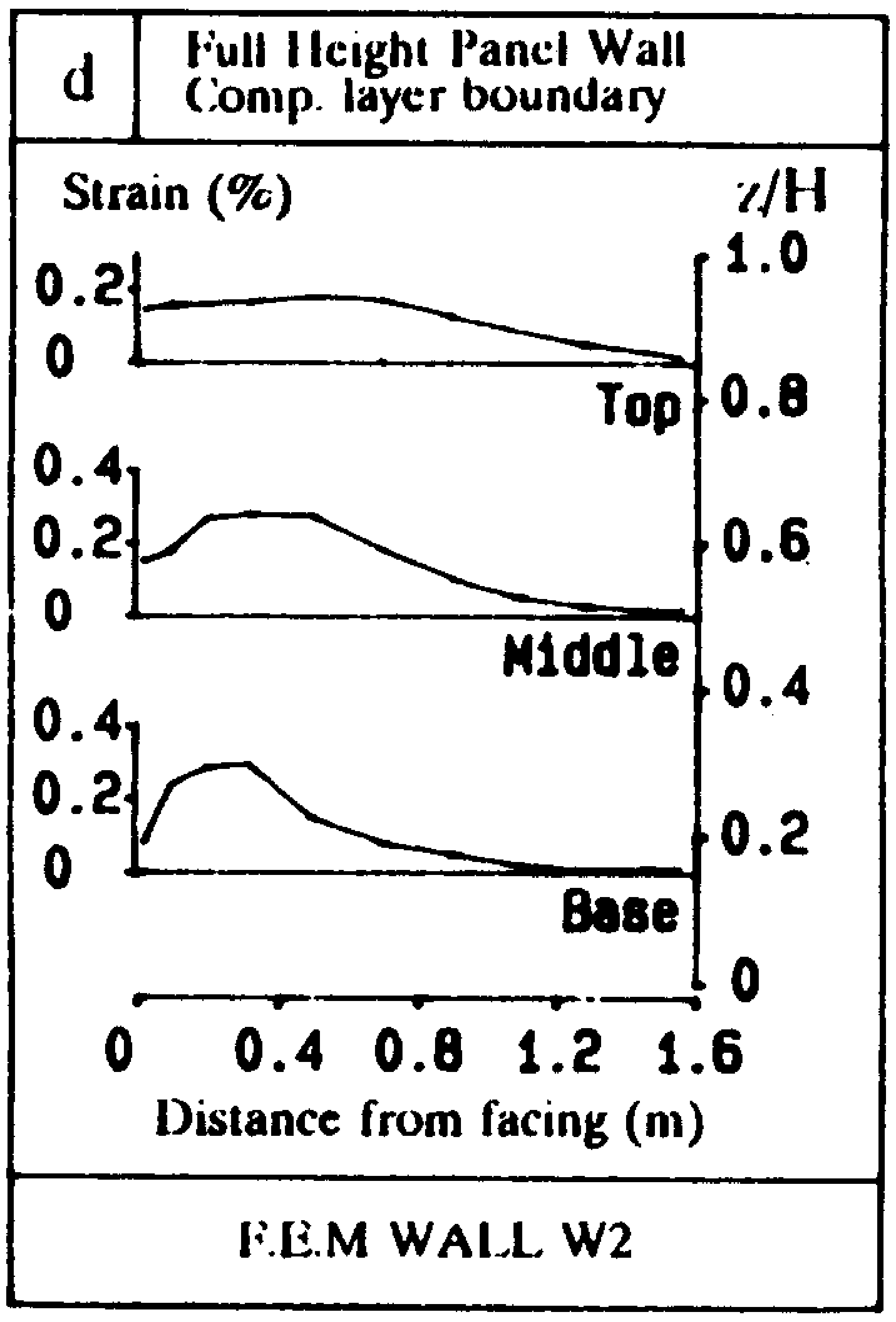
Figure 3 shows a comparison of measured and predicted tensile strain distributions along the reinforcements of the three walls after removing the props.

The tightening of the connections to the timber panels has caused high tensile strains to develop in the zone adjacent to the facing as shown in the Figure. High tensile strains in this zone may be undesirable since the connections are normally the weakest link in the system. However, the tensile strains along the reinforcements of W1 in this zone were higher than the









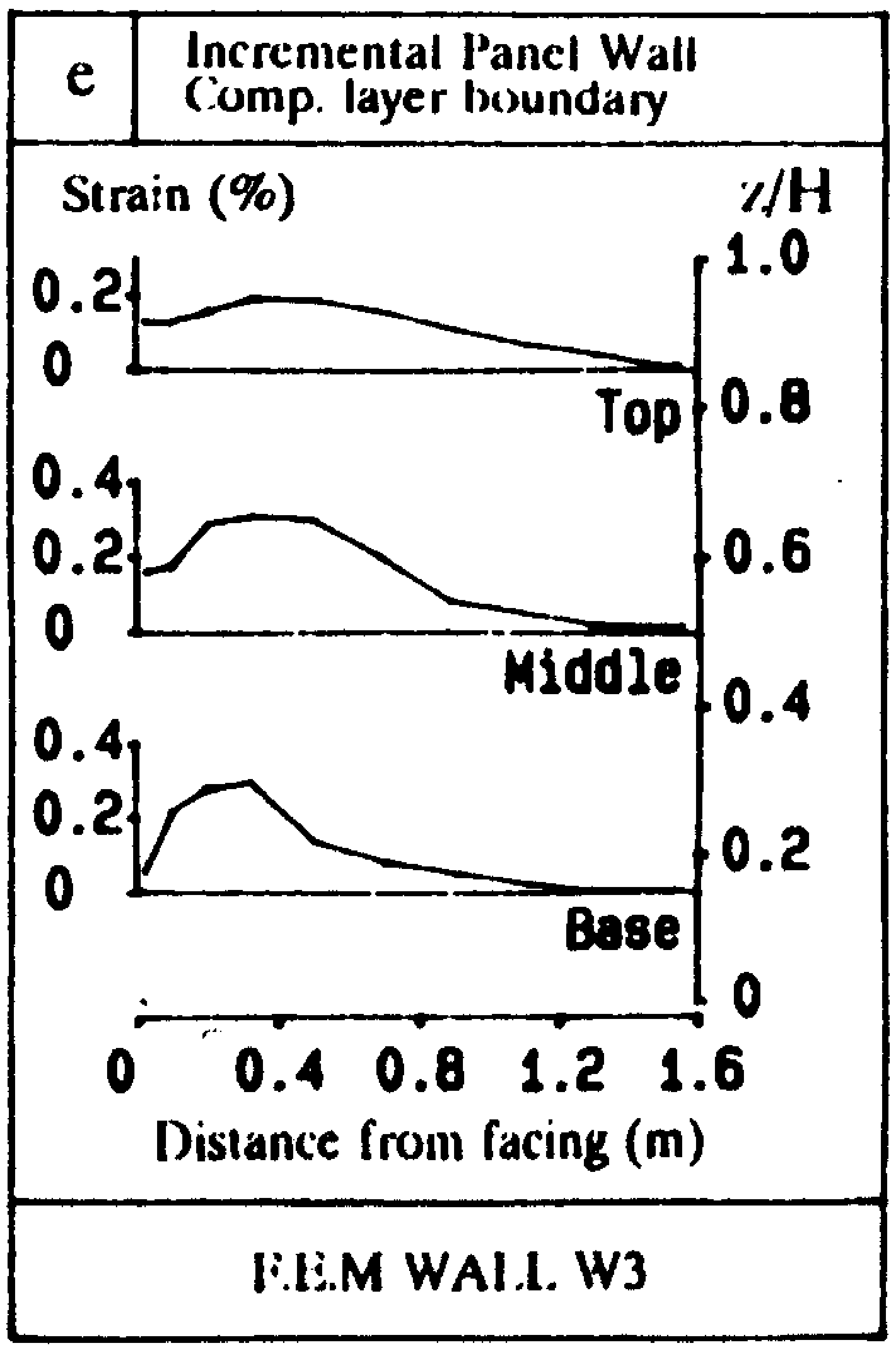


Fig.3 Strain distributions along the reinforcements. (a), (b) and (c): Experimental resuls, (d) and (e): Finite element model.

corresponding strains of both W2 and W3. The tensile strain distributions along the rest of reinforcements of W1 were lower than those of both W2 and W3. These results imply that the presence of the compressible layer improved the distribution of the tensile strains along the reinforcements. No significant difference was observed between the results obtained from both W2 and W3.

Figure 3 shows that the numerical simulation consistently yielded a lower tensile strain distributions along the areas of the reinforcements furthest from the wall. This behaviour is attributed to the assumption of

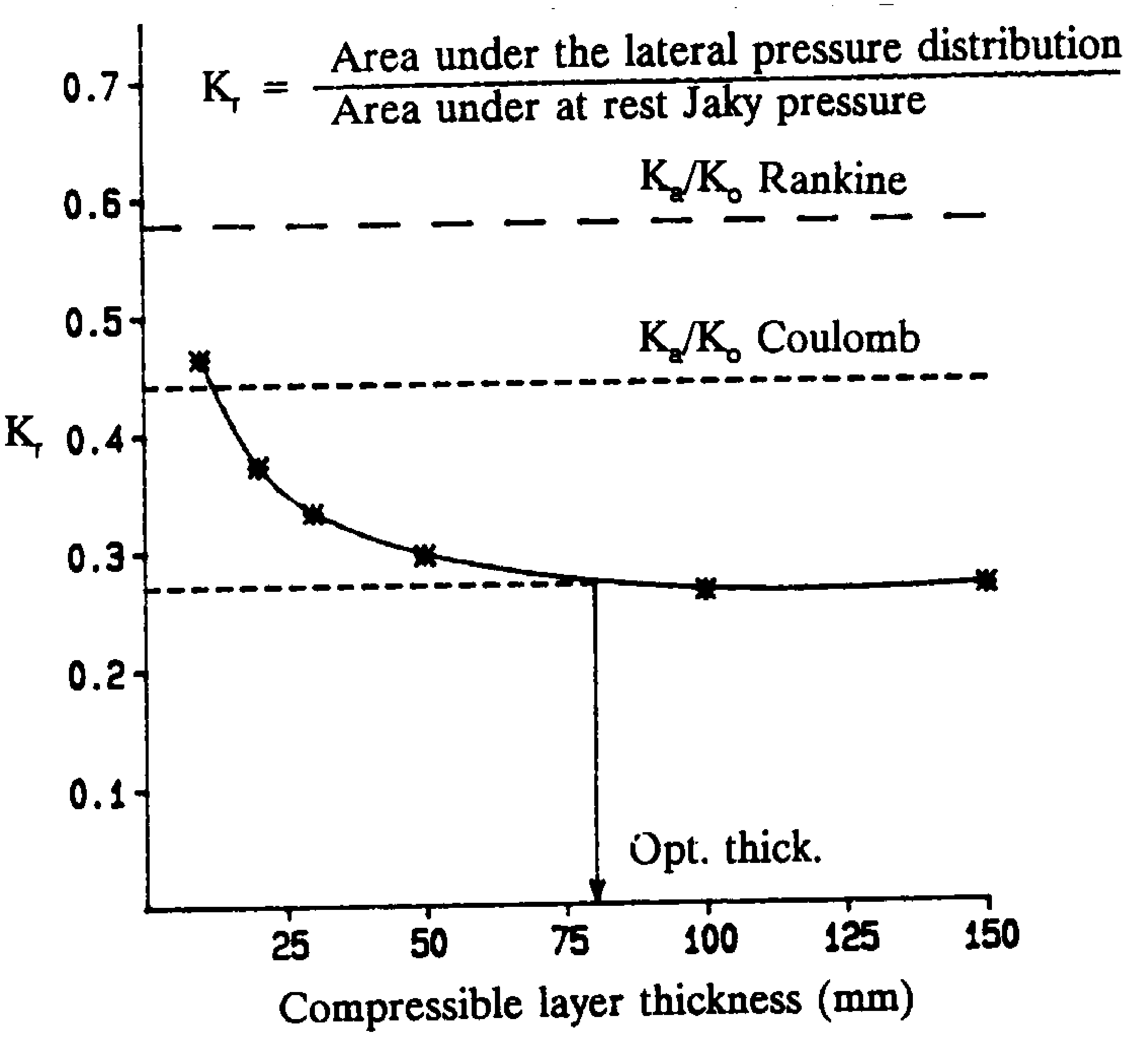


Fig.4 The effect of the thickness of the compressible layer on the earth pressure coefficient ratio (K_r).

constant parameters along the reinforcements. However, the magnitudes and locations of the maximum strains in the reinforcements were reasonably predicted.

5 CONCLUSIONS

The results indicate that the lateral earth pressure on the facing during and after the construction is greatly reduced when using a compressible layer (i.e. low lateral stiffness). It optimises the mobilisation of the soil strength and the strains along the geogrid. As a result of the small lateral pressures at the end of construction and post construction, movement of the panels was reduced. Moreover, the choice of the construction method (i.e, full panel or incremental panel walls) has a negligible effect on the behaviour of reinforced soil walls containing a compressible lateral boundary.

Figure 4 shows that there is a minimum thickness of the compressible layer above which no more reduction in the lateral earth pressure is possible. This chart can be extended to account for different compressibility, configuration, and the backfill material.

The compressible layer may be used to construct new self supported walls, bridge abutments where movement are restricted, and rigid basement walls. It can provides drainage (so producing further reduction in the imposed stresses by lowering the ground water table), thermal and sound isolation, and cushioning functions (vibration absorbtion of dynamic or live loads).

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