Modelling Construction Effects in Polymeric Grid Reinforced Soil Walls

I. Yogarajah
L&M Geotechnic Pte. Ltd, Singapore

K. Z. Andrawes
University of Strathclyde, Glasgow, UK

ABSTRACT: Finite element techniques are used to model two reinforced soil walls with different methods of construction, a full-height panel wall and an incremental panel wall. The results, in terms of lateral pressures and distributions of load and strain along the reinforcements, are compared with experimental data obtained from large instrumented reinforced soil walls using geogrids. The comparison highlights the effects of compaction and the resulting locked-in strains in the geogrid and the importance of taking these into account when simulating the construction effects in the finite element model.

1 INTRODUCTION

The use of finite element method for the analysis of soil structures has been gaining momentum in the last few years. The advantage of this method of analysis is the ability to gain an insight of the behaviour of the soil/structure interaction, which would otherwise seem difficult. With the development of new elements and models, the various complex conditions are now being widely examined.

It is however important to note that the finite element methods are numerical techniques in which accurate modelling of the behaviour plays a vital role in the validity of the solution. It is thus important to develop an understanding of the system behaviour including the effects of construction (Andrawes et al., 1993 and Andrawes & Yogarajah, 1994).

This paper attempts to show how the use of finite element methods for the analysis of reinforced soil walls, without a full understanding of the soil/structure interaction and the overall effects of construction, could lead to erroneous results. Specific attention is placed on accurately modelling the soil/reinforcement interaction. Two walls with different methods of construction are modelled and the results obtained from the analysis are compared with experimental data obtained from large instrumented reinforced soil walls. Variations in the results obtained from the experiments and the finite element analysis are discussed, and methods of overcoming the errors are presented.

2 EFFECTS OF CONSTRUCTION PROCEDURES

In soil retaining walls, the effects of compaction plays an important role in the overall performance. Aggour and Brown (1974), Broms (1971), Ingold (1979, 1980, 1981) have shown that the assumption of at-rest lateral earth pressures at the back of rigid retaining walls is an underestimation of the lateral stresses if compaction is employed, as during compaction large locked-in stresses are developed within the soil mass. These locked-in stresses may be mathematically calculated (Ingold, 1980 and Murray, 1980). In finite element modelling, these compaction forces are usually accounted for by imposing lateral forces along the retaining walls or alternatively by developing equivalent mathematical models which reflect the compaction efforts, Duncan and Chang (1970).

In reinforced soil retaining walls, the effects of compaction procedures are slightly more complex. In addition to the soil experiencing locked-in stresses, the reinforcement also experiences similar locked-in stresses. The combined mechanism, of these stresses, has been detailed by McGown et.al (1990). They showed that when synthetic polymeric grid reinforcements are subjected to compaction forces the soil particles are forced into the apertures of the grids. When the compaction load is released, the grid attempts to return to its initial condition, but is prevented by the particles within the apertures. This results in the development of locked-in strains within the geogrid which increase the confining stress within soil, thus reducing the lateral earth pressures on the facing. The magnitude of the strain depends on the resilient nature of the reinforcement and the integrity of their junctions.

3 EXPERIMENTAL PROCEDURES

Two walls with different methods of construction (a full-height panel wall and an incremental panel wall) were constructed to study the effects of construction and compaction in reinforced soil walls. Full details of the experimental procedures are given in Yogarajah (1993) and only a brief descriptions is provided here.

The walls were each 1.8m high and 1.8m wide and reinforced with three layers of Tensar SR80 geogrid placed at heights of 0.27m, 0.9m and 1.53m from the base. Leighton Buzzard sand consisting of predominantly spherical sand size particles with a very small amount of silt size particles was used. Shear box and triaxial tests on the sand were carried out at a dry unit weight of 16.4kN/m^3. From these, a representative peak angle of friction (ϕ'_p) of 47° and a constant volume angle of friction (ϕ'_{cv})of 34° were determined.

Lateral earth pressures were measured using pressure cells placed on the facing, while loads and strains along the three layers of reinforcements were measured using load cells and strain gauges.

For the full-height panel wall, the facing was propped at 0.3m, 1.0m and 1.6m from its base. While the backfill was placed and compacted, the geogrid layers were placed at the respective levels and left unattached. With the fill at full-height, the reinforcement clamps were hand-tightened to the facing without reducing the loads on the props. The props were then removed and the lateral thrust on the facing was supported by the reinforcements only.

For the incremental panel wall, the first panel was placed and supported at 5 points. When the fill had been placed and compacted to the full-height of the panel, the reinforcement clamps were hand-tightened to the facing without reducing the loads on the props and the props removed. The same sequence was repeated for the second and the third panels taking the wall to the full-height.

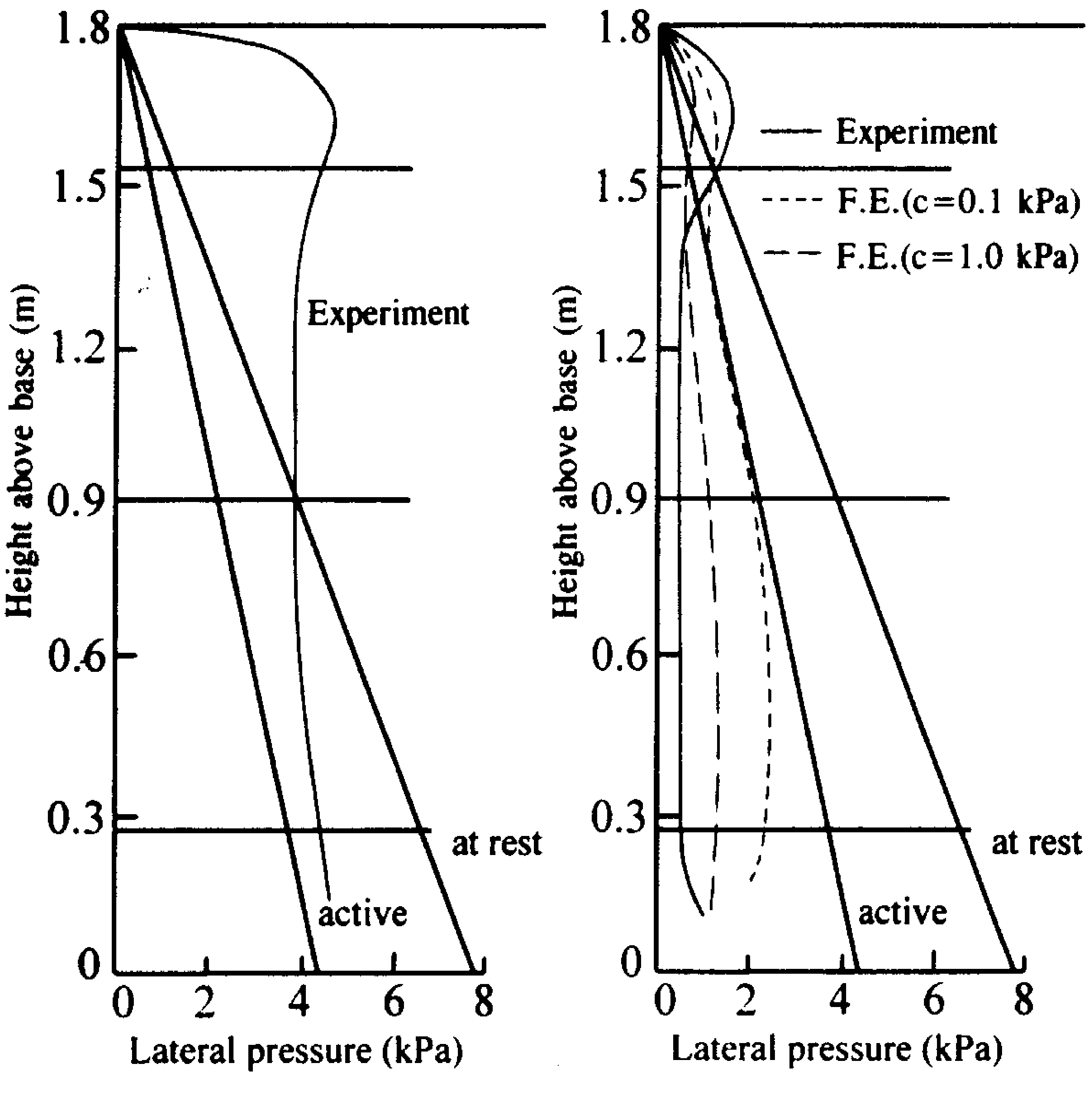
4 EXPERIMENTAL RESULTS

4.1 Full-height panel wall

Figure 1(a) shows the lateral earth pressure distribution when the fill was at full-height before all the props were removed. The lateral earth pressures at the top 0.9m of the wall were higher than the at-rest earth pressures, while at the lower half of the wall, the pressures were lower than the at-rest pressures. The facing displacements recorded were negligible, thus full rigidity of the wall may be assumed. Small loads and strains were recorded along the length of reinforcements.

The reduction in earth pressure at the lower half of the wall is caused by the locked-in strains along the geogrid as suggested by McGown et.al. (1990). The confining stress developed within the soil may be assumed to have a strengthening effect, similar to a pseudo-cohesive effect.

When the props were removed, the lateral earth pressures reduced throughout the height of wall, Fig. 1(b). The pressures were lower than the active earth pressures in the lower 1.3m of the wall and higher than the active earth pressures in the top 0.3m. Loads and strain distributions along the length of reinforcement were not-uniform, with small values recorded near the facing, increasing to a peak value approximately 0.35m from the facing and subsequently reducing to zero at the rear of the reinforcement, Figs 2 and 3.



(a) (b)

Fig.1 Full-height panel wall - Lateral pressure distribution. (a) Before removal of props, (b) After removal of props.

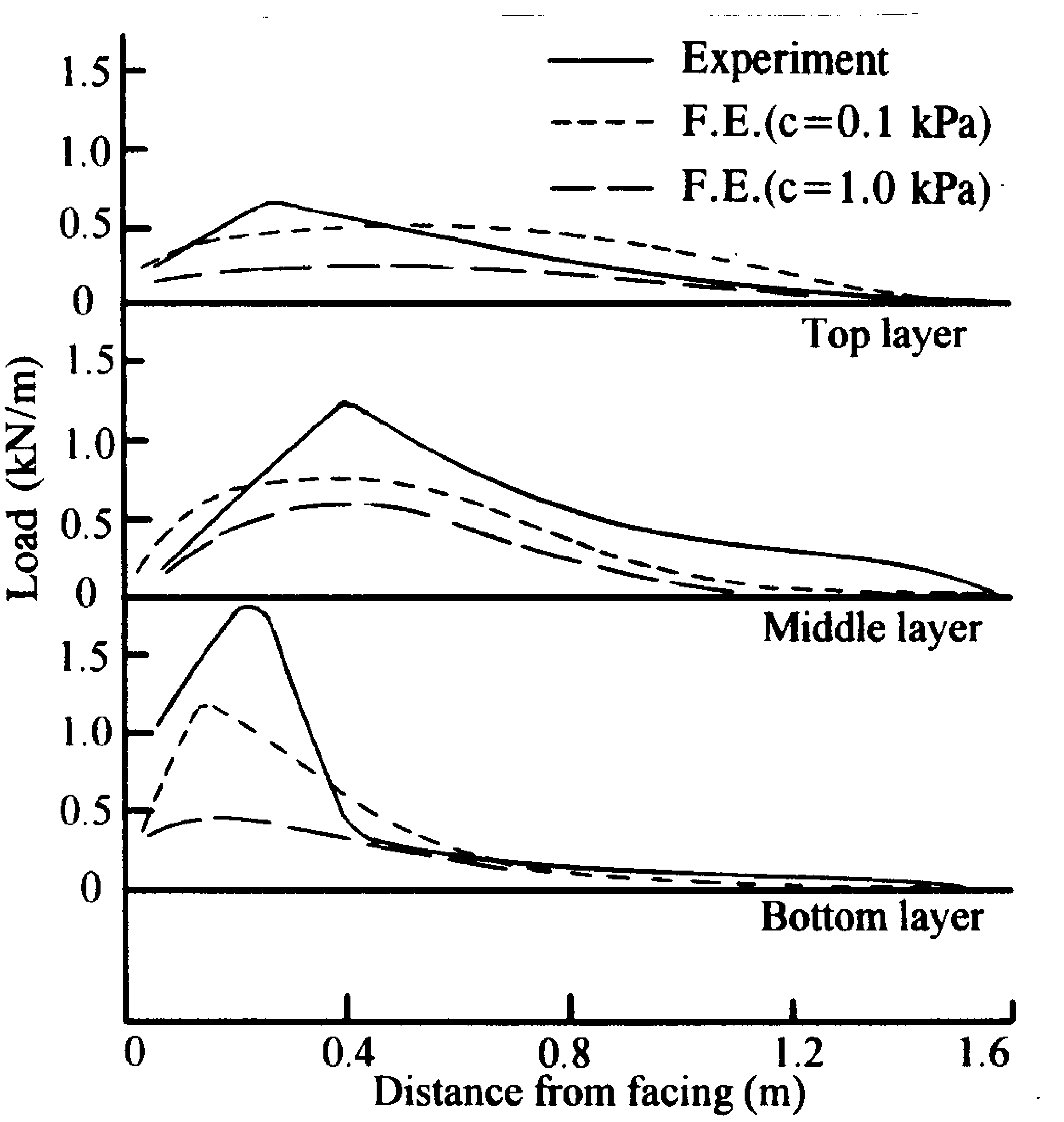


Fig.2 Full-height panel wall - Load distribution along the reinforcements.

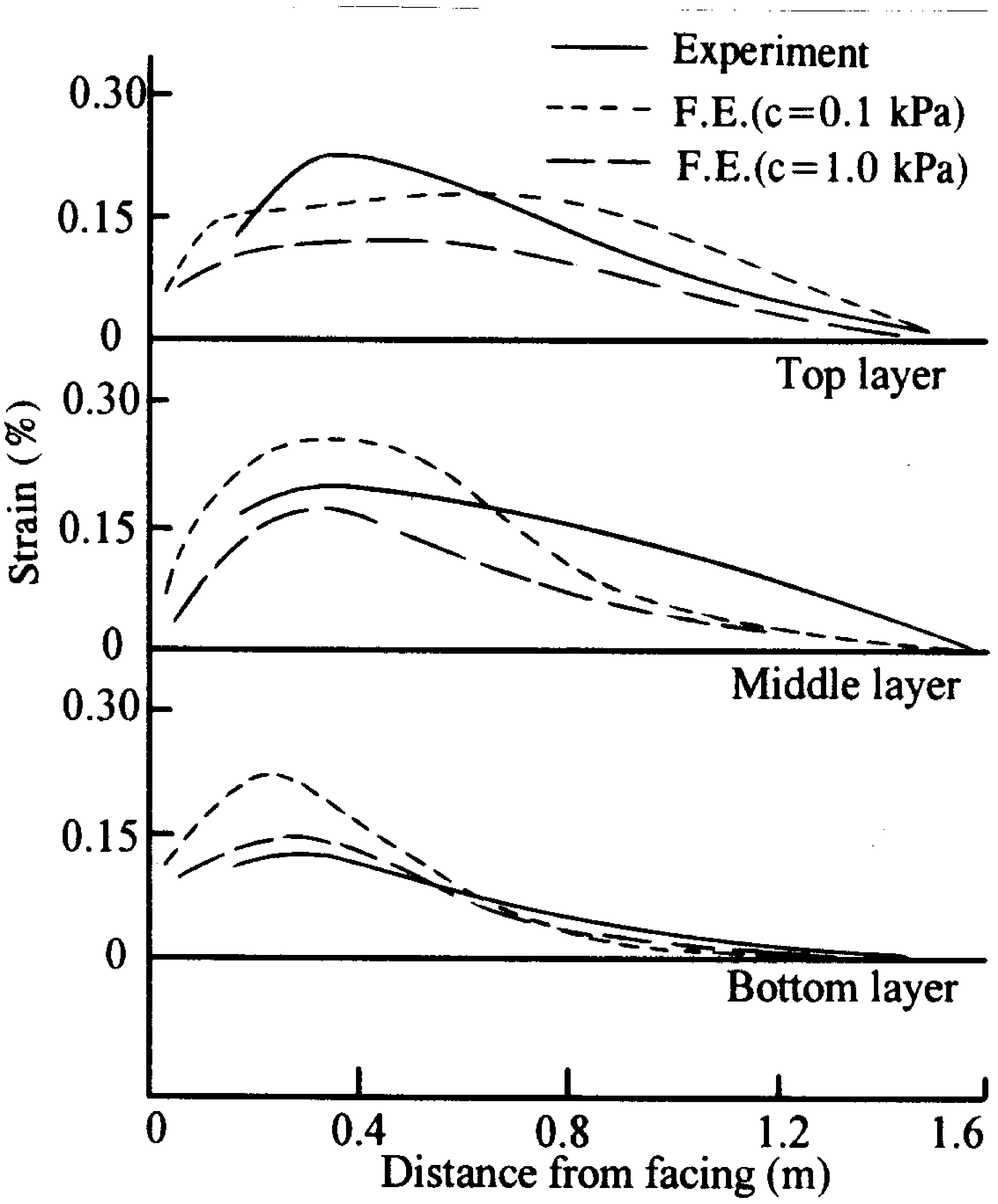


Fig.3 Full height panel wall - Strain distribution along the reinforcements.

4.2 Incremental panel wall

In this wall, the horizontal earth pressures on the rear of each of the panels, whilst they were propped, were greater than the at-rest values. On attaching the reinforcement to the panel and the removal of the props, the earth pressures reduced but remained higher than the at-rest values along the upper one-third of the panel, while below this point the pressures were approximately equal to the active earth pressures values. Additionally, the compaction forces used had the effect of increasing the horizontal earth pressures on the top half of the unsupported panel directly below the propped panel. Figure 4 shows the lateral earth pressure distributions on the facings before and after the removal of the props at the top panel respectively.

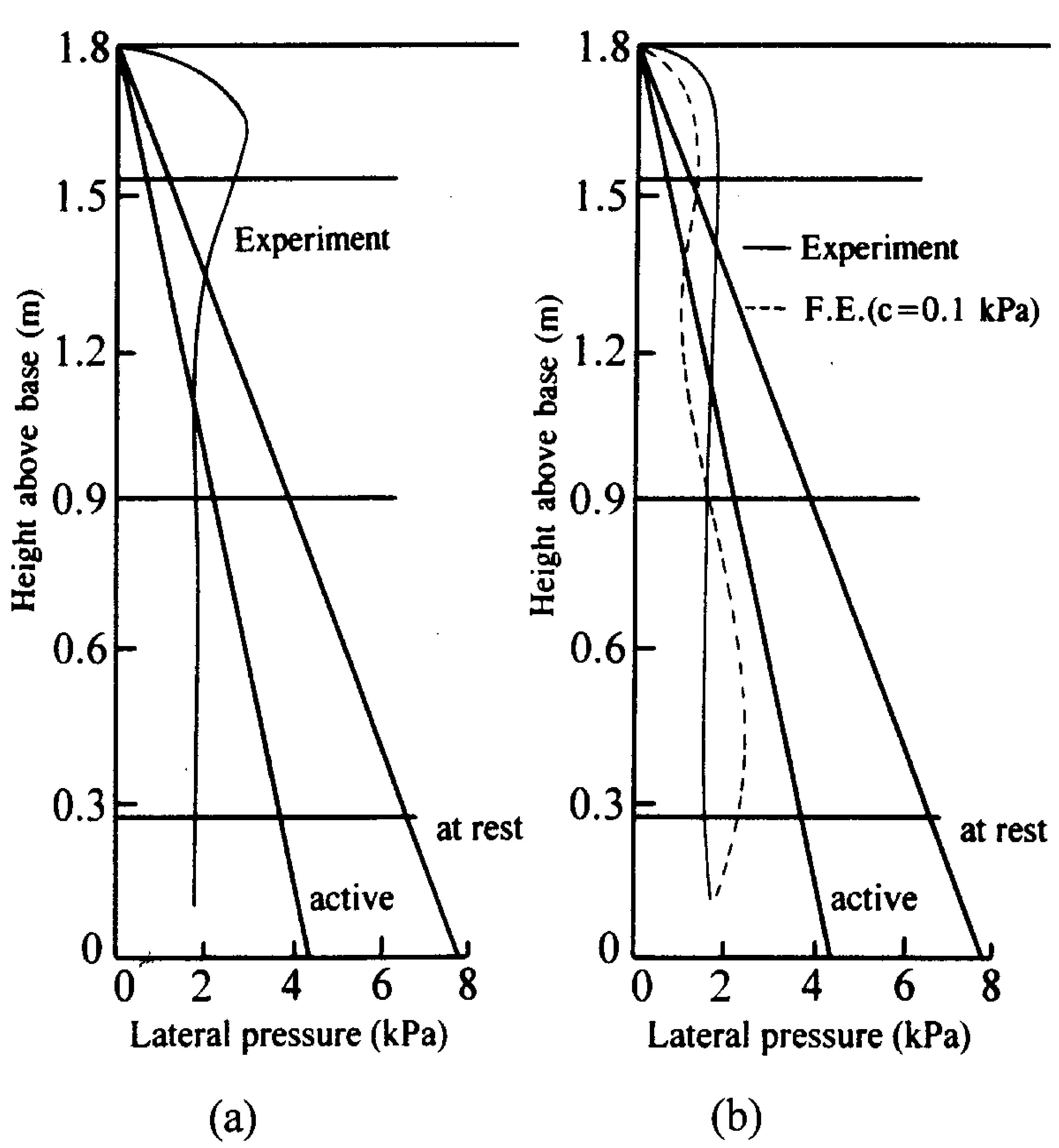


Fig.4 Incremental panel wall - Lateral pressure distribution. (a) Before removal of the props at top panel, (b) After removal of the props at top panel.

The load and strain distributions along the reinforcement layers are shown in Figs. 5 and 6 respectively. As in the case of the full-height panel wall, with the backfill at the height of the panel under construction but before prop removal, the strains were small in the layer of reinforcement associated with this panel. After attachment of the reinforcement to the facing panel and removal of the props the strains increased. Larger strain and load increases were recorded when the panel directly above was completed, and the props to the panel were still in place. The strain and load distributions along the reinforcements were not uniform, with peak values occurring approximately

0.35m from the rear of the facing panels.

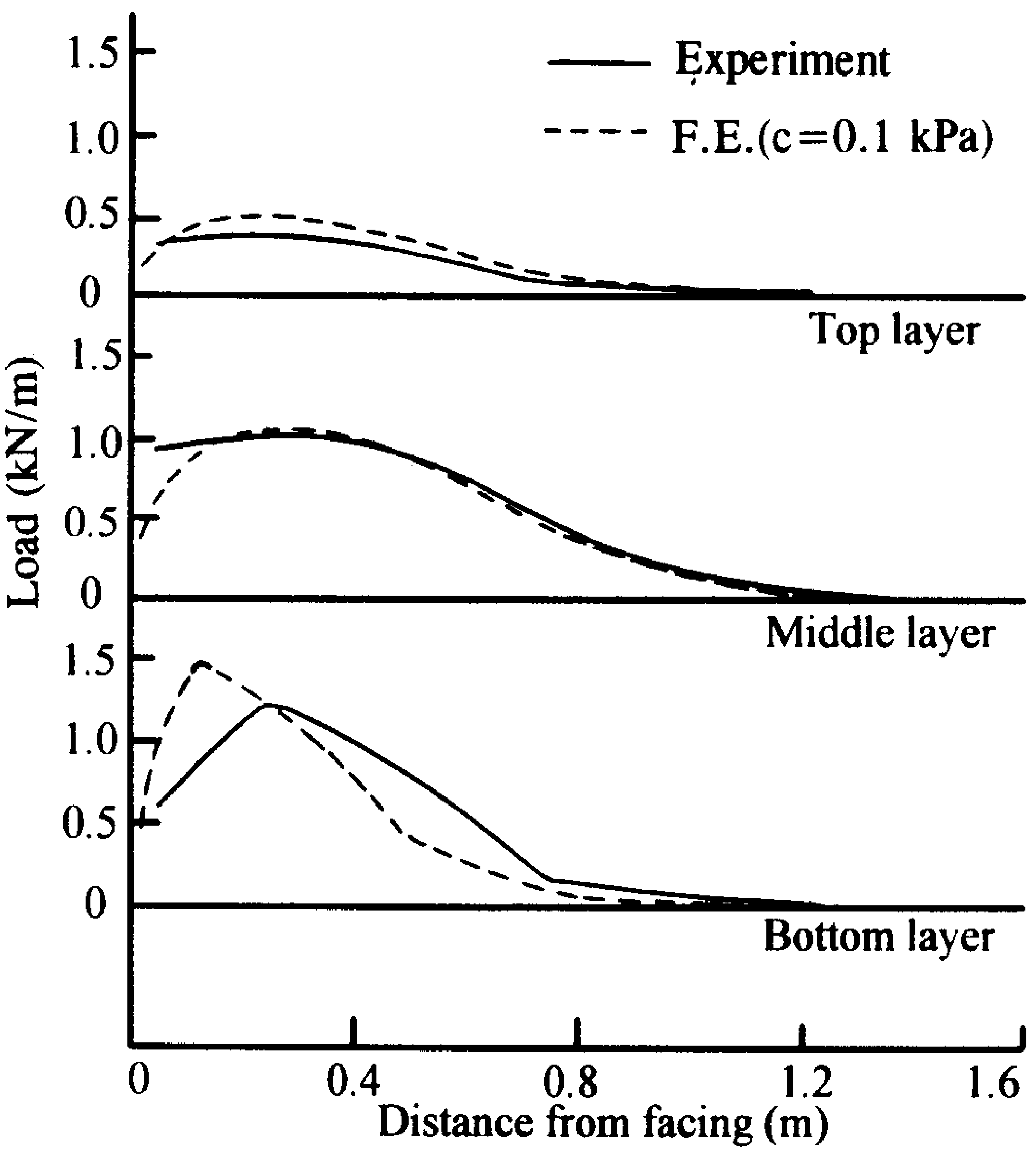


Fig.5 Incremental panel wall - Load distribution along the reinforcements.

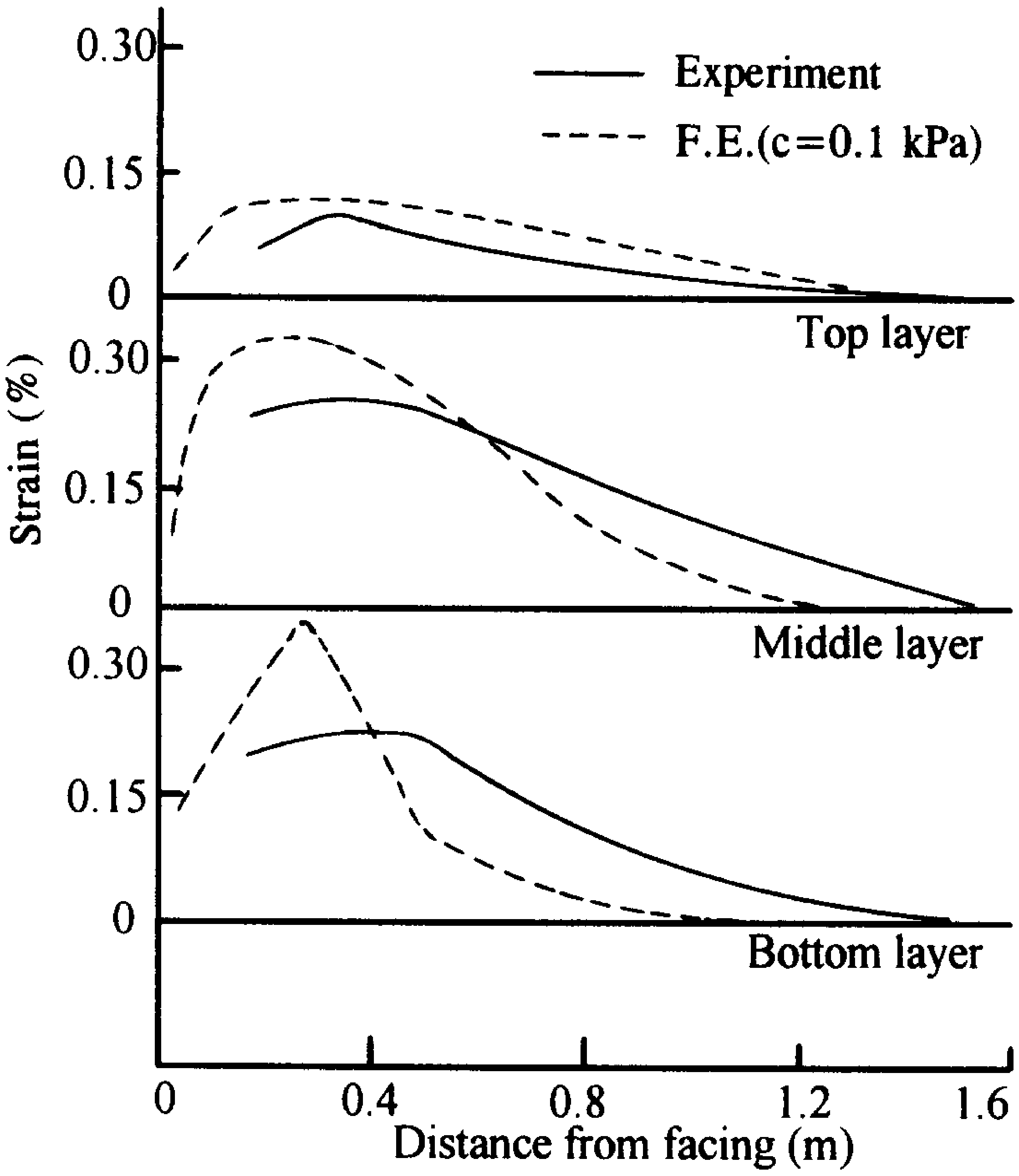


Fig.6 Incremental panel wall - Strain distribution along the reinforcements.

In the incremental panel wall, when the panel under construction is supported, the reinforcements experience locked-in strains. However, when the supports are removed and the panel above it is constructed, the reinforced soil mass is allowed to strain and the locked-in strains are reduced or overcome. Therefore unlike the full-height panel wall, where the reinforced soil mass is allowed to strain only after the props have been removed, in the incremental panel wall, the continuous strains of the reinforced soil mass allows the geogrid to expand and thus reduce or even overcome the locked-in strains within the soil. The effect of 'strengthened' soil in the incremental wall may therefore be insignificant.

5 FINITE ELEMENT ANALYSIS

Modelling of the walls was carried out using the CRISP (Britto and Gunn 1986) finite element package. The finite element mesh used in the study is shown in Fig. 7. The mesh consisted of 420 quadratic elements with 20 elements representing the wall and 400 elements representing the soil. The shear interfaces along the various surfaces were represented by 163 interface elements and the reinforcing elements were represented by 47 bar elements. The wall was assumed to behave as a linear elastic material and the elements representing the soil were assumed to obey Mohr-Coulomb yield criterion. Reinforcement elements were assumed to behave as bi-linear elasto-plastic material while the Goodman et al. (1968) joint element with a Mohr-Coulomb yield criterion was used for the interface elements. The elements connectivity arrangements at the wall/reinforcement connection and at the free end of the reinforcement are shown in Fig. 7 as details A and B.

5.1 Element Properties

From the experimental load and strain distributions, each layer of reinforcement was observed to be experiencing changing elastic moduli throughout the length. As applying a separate elastic modulus along each section of reinforcement was not practical, a constant overall elastic modulus was applied throughout the length of reinforcement. The elastic modulus of the reinforcement elements were obtained from the ratios of measured load to measured strain from the experiment.

Interface elements with different interface properties (to model the various combinations of material interfaces) were used. Along the soil/reinforcement interface, the properties were obtained from back analysis of pull-out tests using the finite element solution (Yogarajah and Yeo 1993). A coefficient of interaction of 0.9 (Yogarajah 1993) was applied to the peak soil friction angle to obtain the angle of interface friction of 42°.

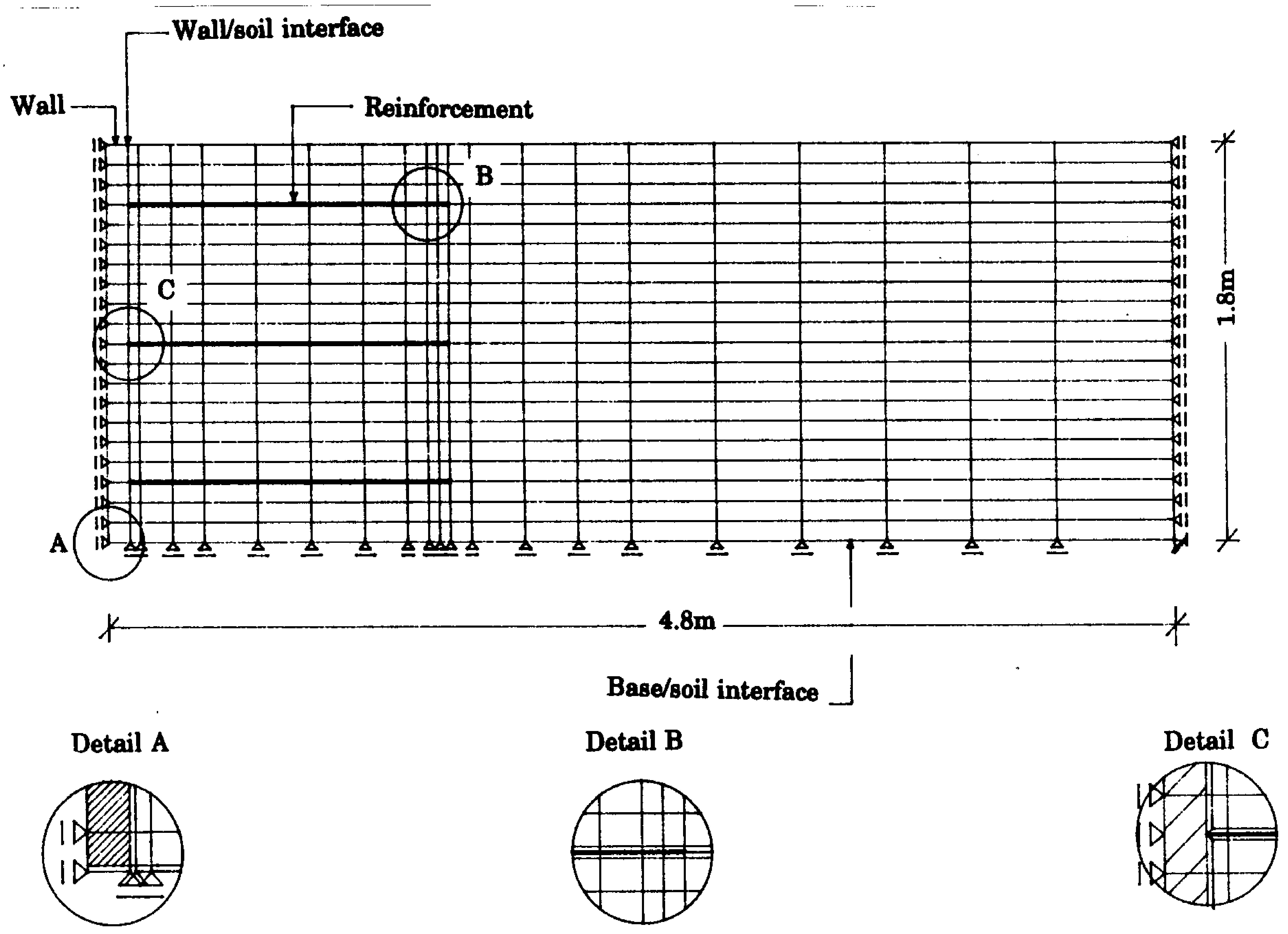


Fig. 7 Finite element mesh used in reinforced soil wall simulation.

At the soil/soil interface the shear modulus was calculated. Friction angles for the base/wall interface was assumed to be 5°, while at the base/soil and the wall/soil interfaces, measured friction angles (using shear box tests) of 30° and 36^{0} were used respectively. The shear moduli for the wall/soil and the base/soil were taken as a ratio of soil/reinforcement shear modulus.

5.2 In-situ stress specification

In the finite element analysis, the lateral earth pressures on the panels, at the end of construction were assumed to be the same as those measured in the experiments. The reinforcement elements were assumed to have zero stresses along the length of the reinforcement. This assumption was thought to have no effects on the final results. Additionally, in a two-dimensional analysis, the three-dimensional effects of interlock is difficult to model. A method of overcoming this problem is discussed below.

6 FINITE ELEMENT RESULTS

The results obtained from the finite element study are plotted against the corresponding experimentally measured data.

Figures 1(b) and 4(b)6 show the comparison of lateral earth pressures from the finite element analysis and the experimental programme for the two methods of construction. For the full-height panel wall, generally higher earth pressures were obtained from the finite element analysis, with largest differences at the base and smaller differences near the top of the wall. In the incremental wall, the lateral earth pressures obtained from the finite element analysis were similar to the measured values.

The variation in results is caused by the methods in which the reinforced soil mass is modelled. In the finite element analysis of the full-height panel wall, the reinforcement and soil elements were treated as separate entities with no interaction imposed with each other throughout the height of the wall. As previously mentioned, the soil mass would have been strengthened due to the placing and compaction of the backfill. The increase in strength suggests that treating the reinforcement and soil element as separate entities may not be valid, especially for the lower half of the wall, and the soil and reinforcement may be required to be treated as a 'working' mass of soil and be given a pseudo-cohesion value.

In the incremental panel wall however, the effect of strengthened soil is not significant as the reinforced soil mass is subjected to a continuous strain path during the wall construction. In this strain path, the locked-in strains developed within the soil mass is much less than the overall strain of the soil. Thus, the reinforcement and the soil may be treated as separate entities.

A second analysis was carried out on the full-height panel wall to model the strengthened soil mass. In this case, all the properties were maintained similar to the initial analysis, but a cohesion of 1kPa was applied to the soil mass. The results obtained are also shown in Fig. 1(b). The lateral earth pressures obtained were more closely matched to the measured values, unlike the initial finite element analysis in which the lateral earth pressures at the base of the wall were higher than the measured values.

Load distributions obtained from the finite element analysis for both walls are plotted together with the measured values in Figs. 2 and 5. The results show generally good agreement in both distributions.

The strain distributions along the reinforcements were calculated by dividing the loads by the elastic modulus. The results are shown in Figs. 3 and 6. The comparison between the experimental and the finite element results are generally in agreement along the top two layers in the walls. In the lower layers of the full-height panel wall however, the strains were at times twice the measured values. The discrepancy may be attributed to the constant elastic modulus used in the analysis whereas the operating elastic modulus in the experiment was variable. In particular, the operating elastic modulus at the bottom layer in the zone of peak strains was approximately 2-3 times greater than the assumed value.

7 DISCUSSION AND CONCLUSION

The effects of construction on the overall behaviour of reinforced soil walls have been detailed for two methods of construction.

In the full-hight panel wall, the reinforced soil mass was confined throughout the construction process. During the construction process, the locked-in strains developed along the reinforcement provided a strengthened soil mass thus reducing the lateral earth pressures on the wall.

The strain path experienced by the reinforced soil mass in the incremental panel wall is different to that of the full height panel wall. In the incremental panel wall, the reinforced soil mass is continuously straining, thus reducing the magnitude of locked-in strains developed along the reinforcement.

When carrying out 2-dimensional finite element modelling of reinforced soil structures, the strengthened soil mass, may be accounted for by applying a cohesion to the soil properties. The value of the cohesion, is dependent on the resilient nature of the reinforcement, integrity of the reinforcements and the compaction efforts.

Not including the effects of construction and incorrect modelling techniques in finite element analysis could lead to erroneous results.

REFERENCES

Aggour, M.S. and Brown, C.B. (1974). The Prediction of Earth Pressure on Retaining Walls due to Compaction. *Geotechnique 24, No.4:489-502.*

Andrawes, K.Z., McGown, A. and Yogarajah, I. (1993). Effects of Construction Techniques on Polymeric Geogrid Reinforced Soil Walls. *Presses Ponts et Chaussees, Paris, ISBN 2-85978-205-2:475-504.*

Andrawes, K.Z. and Yogarajah, I. (1994). Effects of Reinforcement Connections on the Behaviour of Reinforced Soil Walls. *8th Intl. Conf. of the Assoc. for Computer Methods and Advances in Geomechanics, W.Virginia, USA. (In press)*

Britto, A. and Gunn, M.J. (1986). *Crisp Users and Programmers Manual.* Cambridge University.

Broms, B.B. (1971). Lateral Earth Pressure Due to Compaction of Cohesionless Soils. *Proc. 4th Int. Conf. Soil Mech. and Fdn, Eng., Budapest, pp. 373-384.*

Duncan, J.M. and Chang, C.Y. (1970). Non-Linear Analysis of Stress-Strain Behaviour in Soils. *Journal of Soil Mechanics and Foundation Division, ASCE, Vol 96, SM 5:1629-1653.*

Goodman, R.E., Taylor, R.L. and Brekke, T.L. (1968). A Model for the Mechanics of Jointed Rocks. *Journal of Soil Mechanics and Foundation Division, ASCE, 94:637-659.*

Ingold, T.S. (1979). The Effects of Compaction on Retaining Walls. *Geotechnique, 29:265-283.*

Ingold, T.S. (1980). Reinforced Earth Theory and Design. *Journal of the Highway Engineer, July, pp 265-283.*

Ingold, T.S. (1981). A Laboratory Simulation of Reinforced Clay Walls. *Geotechnique, 31:399-412.*

McGown, A. Yeo, K.C. and Yogarajah, I. (1990). Identification of a Dynamic Interlock Mechanism. *Int. Reinforced Soil Conference, University of Strathclyde, Glasgow, UK.*

Murray, R.T. (1980). Retaining Wall Performance During Backfilling. *Proc. ASCE, Journal of Geotech. Eng. Div. Vol 106, GT 9:1062-1066.*

Yogarajah, I. (1993). *Effects of Construction Procedures on the Behaviour of Geogrid Reinforced Soil Walls.* PhD. Thesis, University of Strathclyde, Glasgow.

Yogarajah, I. and Yeo, K.C. (1993). Finite Element Modelling of Pull-out Tests With Load and Strain Measurements. *Geotextiles and Geomembranes, 13:43-54.*