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Development of horizontal earth pressures and behaviour of single and multi segmented walls

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ABSTRACT: Reinforced soil structures have been employed in the Civil Engineering field over the past twenty-five years. Of late, a large amount of attention has been channelled to the use of multi segmented walls as opposed to single segment walls, as the former system allows rapid construction. However, the use of these systems may be detrimental to the reinforced soil concept if not employed properly. The overall behaviour, especially the development of horizontal earth pressures may vary greatly. This paper looks at the behaviour of these walls paying attention to the horizontal earth pressures developed on the walls.

1 INTRODUCTION

Reinforced soil structures have been employed in the Civil Engineering field over the past twenty years. During this time, advances have been made both in the design and construction concepts of the systems, in order to allow them to be employed to its optimum capability. Of late, a large amount of attention has been channelled to the use of multi segmented walls (aka. incremental panel wall) as opposed to single segment walls (aka. full-height panel wall). In multi-segmented walls, small usually manhandleable sized blocks are stacked one above the other with reinforcement layers installed at required levels to form a reinforced soil wall. The advantage of this system over previously employed single segment walls is the ease with which high walls may be constructed with little or no lifting machineries and at times at very fast rates. As the constructions methods for the single and multi segmented walls are different, the development of horizontal earth pressures and therefore behaviour of the systems vary.

To determine the overall difference of behaviour of single and multi-segmented walls, two large full-scale instrumented walls were constructed with single and multi segmented wall units. The walls were fully instrumented to measure horizontal earth pressures along the face and load and strain measurements along the reinforcement.

This paper addresses the development of earth pressures on the wall facing and overall behaviour of single and multi-segmented walls. Details of the difference of horizontal earth pressures together with the loads and strains along reinforcements are highlighted. The results show that contrary to popular belief, the horizontal earth pressures developed in multi segmented walls are substantially higher than single segment walls. The reasons for this large earth pressures are highlighted.

2 EXPERIMENTAL PROCEDURES

Two large scale tests were carried out to determine the behaviour of polymeric reinforced single and multi segmented wall units. The apparatus consisted of a tank 4.8m long, 1.8m wide and 2.0m high. Three sides of the tank were covered with rigid steel plates, while the front end was left open for the wall facing panels. The single and multi segmented wall panels used for the facings are shown in Figs. 1 and 2. Three layers of geogrid reinforcements at 0.63m spacing were used in all of the retaining walls.

For the single segment wall, the three panels were placed vertically, with the 0.7m wide panel positioned between the two 0.55m wide panels, and fully propped during the construction process. For the multi-segmented wall, the panels were placed horizontally with the 0.7m panel located between the two 0.55m panels and they were only propped until the fill reached the top of each panel, thereafter, the props were released. On the sides and base of the

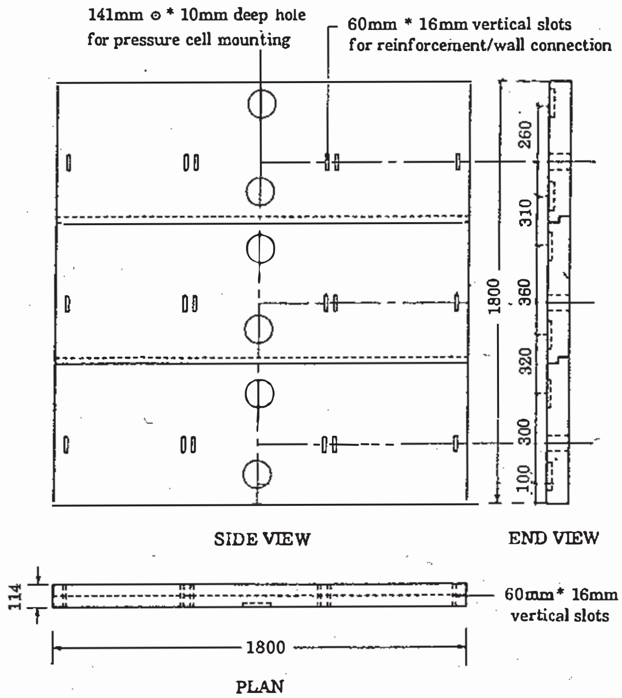

Fig. 1 Multi-segmented wall facing unit

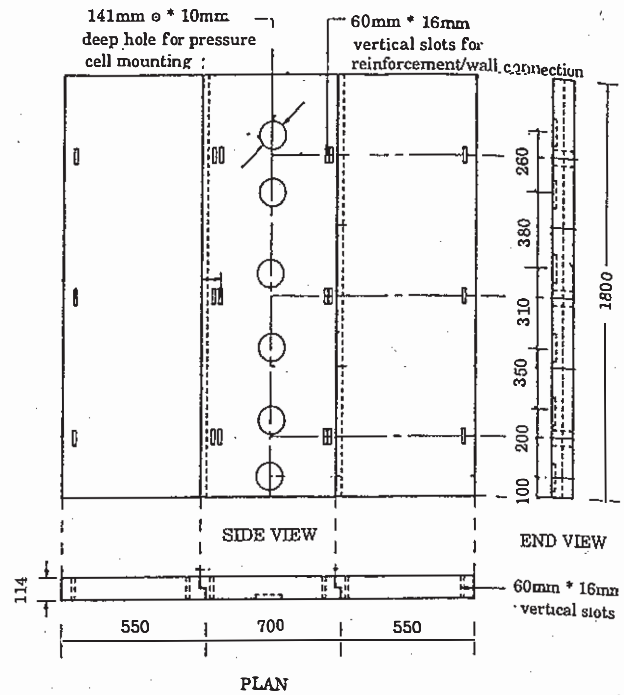

Fig. 2 Single segment wall facing unit

facing panels abutting the tank sides, greased rubber membranes were placed between the wall and the tank to reduce friction and allow the wall to be free-standing, only supported by the reinforcement layers. Along the centre of the wall, six pressure cells were placed flush with the facing. The reinforcements were attached to the facing through elongated holes along the sides of the panels. The elongated holes also allowed the vertical movement of the reinforcement layers.

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 the dry unit weight used in the large scale wall tests of 16.4kN/m^3 (relative density of 82%). From these, a representative peak angle of friction (φ_p) of 47^o and a constant volume angle of friction (φ_{cv}) of 34^o were measured. The geogrid reinforcement used was Tensar SR80, placed perpendicular to the facing at heights of 0.27m, 0.9m and 1.53m from the base.

The in-situ density of the backfill was achieved using a Kango hammer fitted with a 0.3m square plate of weight 0.21kN (0.71kN/m). Compaction of the backfill was carried out in layers of 135 - 175mm thickness parallel to the wall facing starting from the area next to the wall.

Loads and strains along the geogrids were measured using specially designed load cells and strain gauges respectively. The load cells were connected to the geogrids using 1mm thick mild steel plates. Six load cell and strain gauge positions were used. Strain gauges were attached at various points to form full Wheatstone bridges.

3 CONSTRUCTION PROCEDURES

3.1 Single Segment Walls

The three single segment panels were set vertical at the front of the tank. Each panel was supported horizontally at 0.3m, 1.0m and 1.6m heights from its base. The backfill was placed and compacted. At the level of reinforcement, the geogrid layer was placed perpendicular to the facing 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 supported by the reinforcements.

3.2 Multi-Segmented Walls

The first panel was placed on its longer side, and set vertical at the front of the tank. The panel was supported at 5 points; a short distance away from the four corners and at the centre of the panel. The supports were placed to ensure that the wall did not rotate about any of the diagonal axes or bend during the construction process. As in the single segment panel wall, the backfill was placed and compacted in layers. 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. The props were removed in a systematic sequence, with the two diagonal props lower left and upper right removed first followed by the props at the upper left and lower right. The central prop was removed last. After the removal of the props, the second panel was placed vertically above the first panel and propped in a manner similar to that of the first panel. When the full height of soil had been placed and compacted behind the second panel, tightening of the reinforcement connections and prop removal was undertaken as before. The same sequence was repeated for the third panel taking the wall to the full-height. Thus at any one time, only a single panel was supported.

4 RESULTS

4.1 Horizontal earth pressures

The lateral earth pressures before and after prop removal for the single segment wall at various heights of fill is shown schematically in Fig. 3, together with the Jaky's at-rest and Coulombs and Rankines active earth pressure lines. During construction of the first 0.5H of the wall, the earth pressures increased with height of fill placed. At the end of construction, the horizontal earth pressures were seen to be larger then the at-rest earth pressures at the top 0.5H of the wall and in between the active and at-rest pressures in the lower 0.5H of the wall. At the top of the wall, the high horizontal pressures are caused by the locked-in compaction stresses in the soil, while in the lower end the locked-in strains in the reinforcement suggested by McGown et.al. (1990,1995) is believed to have caused the low horizontal pressures.

When the props were removed, the earth pressures remained larger than the at-rest pressures in the upper 0.25H of the wall and reduced to lower than the active pressures throughout the lower 0.75H of the wall.

The development of horizontal stresses in the multi segmented wall is shown schematically in Fig. 4, detailing the earth pressures at various stages of construction. When the fill was placed and compacted, the horizontal earth pressures were larger than the at-rest earth pressures. As construction proceeded, the horizontal earth pressures for the particular panel reduced when the props were removed. However when the upper segment was placed, the horizontal earth pressures beneath the panel being placed increased. When all the props were removed, the horizontal earth pressures were larger than the at-rest pressures in the top 0.25H of the wall, between at-rest and active pressures at 0.25H to 0.4H and slightly less than the active pressures in the lower 0.6H of the wall.

4.2 Load and strain distributions

The measured strain and load distributions along the reinforcement layers when the backfill was at full height are shown in Fig. 5. Before prop removal or attachment of the reinforcement to the facing, small strains and loads were recorded along all the layers of reinforcements. Maximum strains of 0.05% were recorded along all reinforcements.

In the case of load distributions, peak loads of 0.05 - 0.3kN/m were recorded along the reinforcement layers. The presence of strains and loads in the reinforcements at this stage indicates the presence of an 'interlock' mechanism reported by McGown et.al. (1990,1995) and Yogarajah (1990 and 1993).

After attachment of the reinforcement to the facing units and prop removal, distinct peaks were seen in the values of strains and loads recorded along the reinforcement. The peaks occurred some distance away from the front end of the reinforcement. At the front end, the values were small, increasing to a peak value and subsequently reducing to zero at the rear of the reinforcement. The positions of peak strains in the three layers of reinforcements when traced, followed a vertical line with the locus of the peak strains occurring approximately 0.35m (0.22H, where H is the final wall height) from the rear of the facing panels.

The strain and load distributions along the reinforcement layers of the multi segmented wall is shown in Fig. 6. 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, with maximum strains of approximately 0.02% and maximum loads of approximately 0.1kN/m. After attachment of the reinforcement to the facing panels, the props were removed and the maximum strains increased to about 0.06% and the maximum loads increased to about 0.35kN/m. Larger strain and load increases to about 0.2% and 1.5kN/m respectively were recorded when the panel directly above was completed, and the props

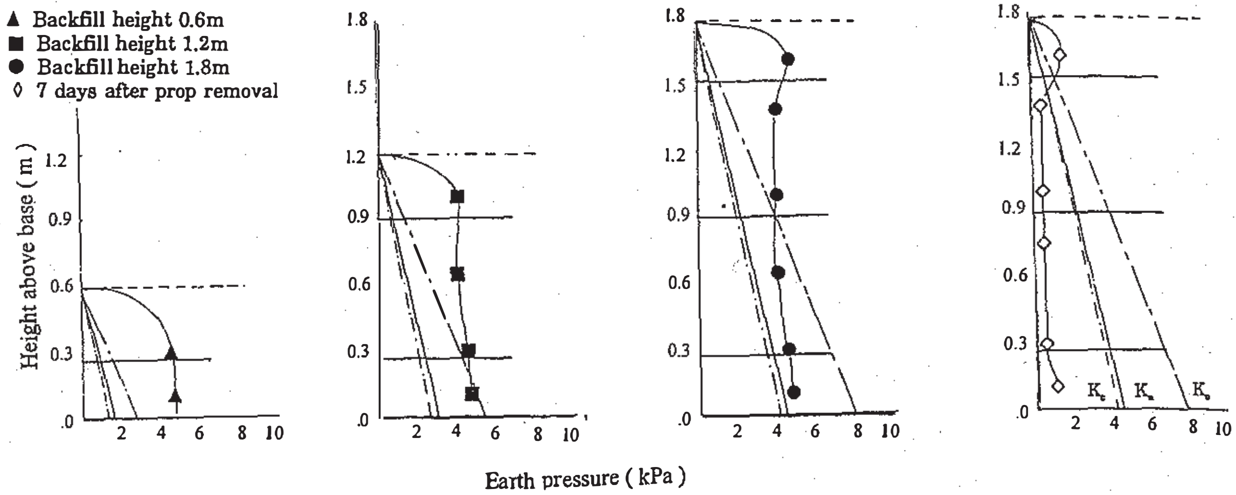

Fig. 3 Horizontal earth pressures on the single segment wall unit

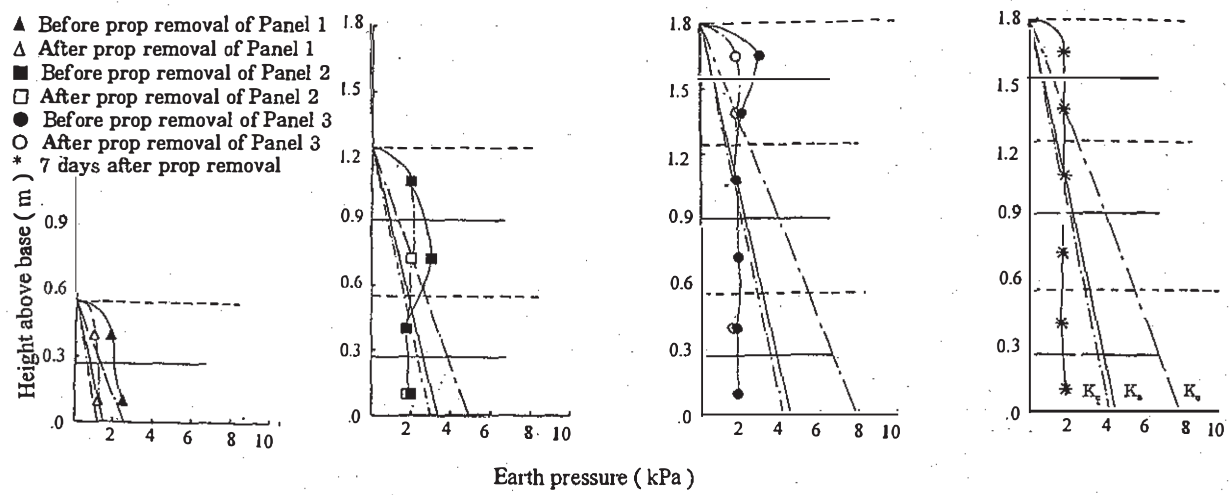

Fig. 4 Horizontal earth pressures on the multi-segment wall unit

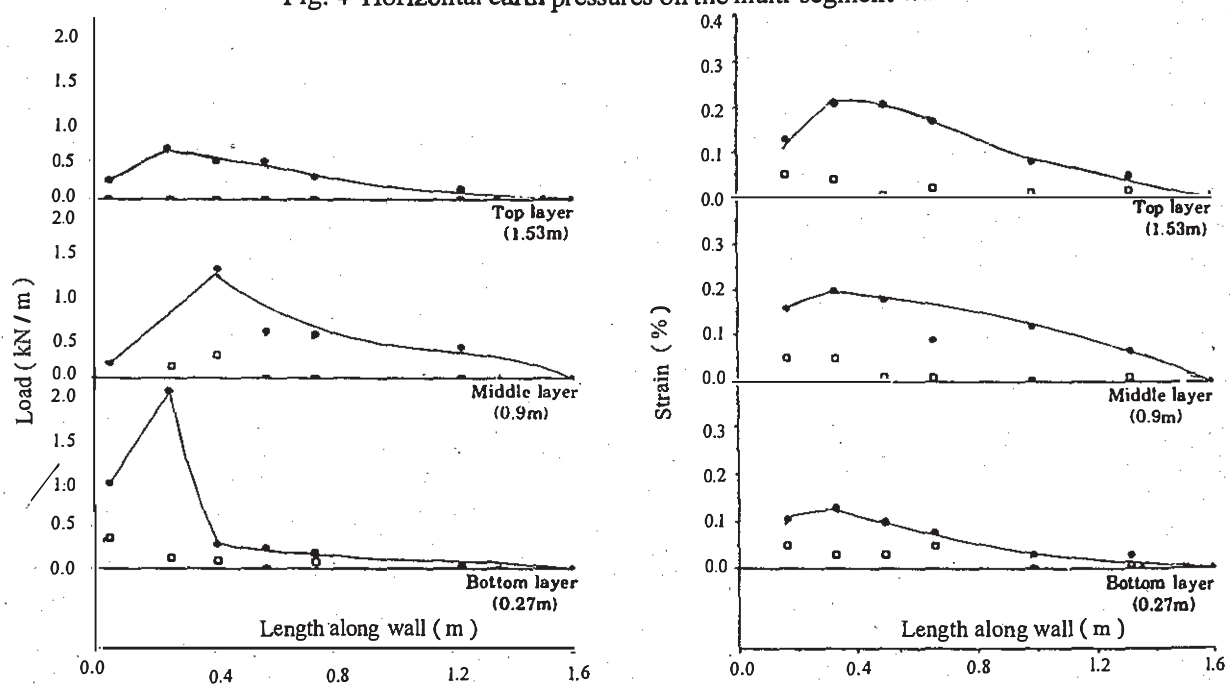

Fig. 5 Load and Strain distribution along reinforcement for single segment wall

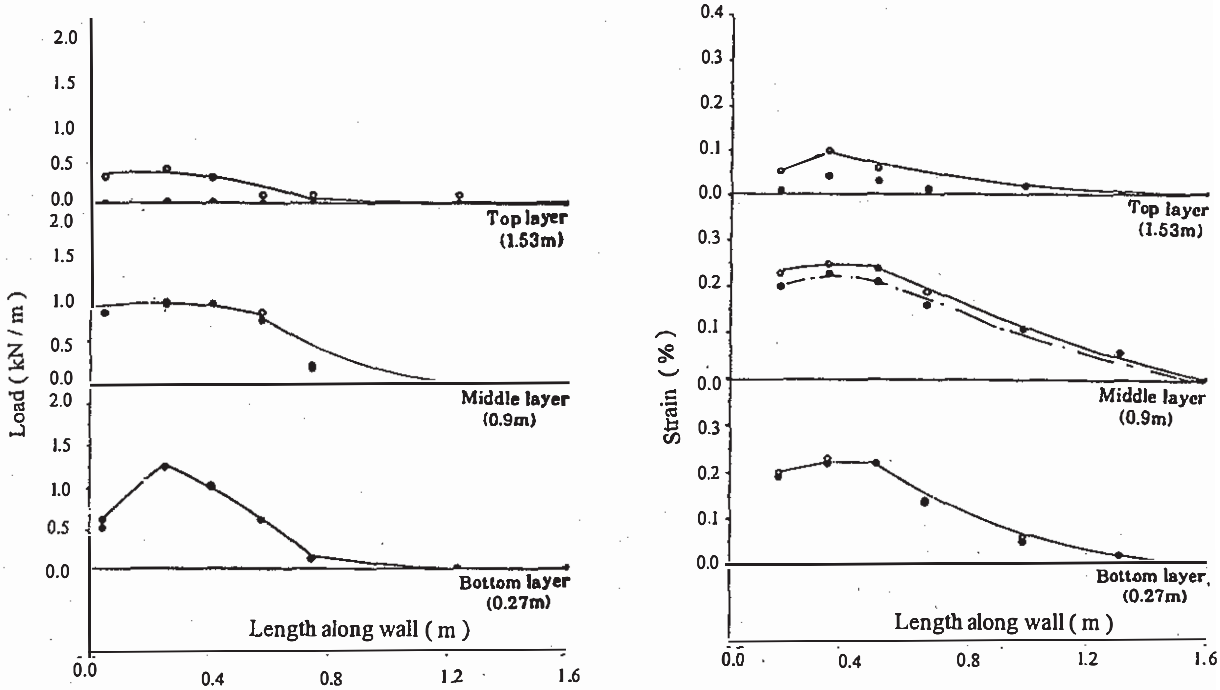

Fig. 6 Load and Strain distribution along reinforcement for multi segment wall

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 (0.22H) from the rear of the facing panels.

5 DISCUSSION OF TEST DATA

For both the single segment and multi-segmented walls, with the fill at full-height but before prop removal, the horizontal earth pressures recorded at the rear of the facing panels were higher than the at-rest earth pressures. This is in agreement with the findings of previous investigators (Broms 1971, Ingold 1979). The horizontal earth pressures acting on the lower half of the single segment walls were nevertheless lower than the theoretical earth pressure at-rest. This is suggested to have been caused by the 'locked-in' strains developed within the reinforcement during compaction.

For the multi-segmented walls, the horizontal earth pressures recorded on the facing panels with the fill at full height, reinforcements attached and props removed, were approximately 1.5 times higher than the earth pressures recorded on the single segment wall. The difference of behaviour may be explained as follows:

a. For the single segment wall, the reinforced soil mass was restrained laterally throughout the construction process. During the compaction process, the reinforced soil mass is subjected to locked in stresses in the reinforcement as well as an overburden pressure. The two components strengthen the soil as in the case of a pseudo-cohesion. This increased strength of soil therefore allow a reduction of earth pressures along the wall facing. When the props are removed, the locked-in stresses together with the strength of the soil allows a low horizontal earth pressure to develop along the wall face.

b. For the multi-segmented walls, only a single segment is propped at any one time, whilst the segments below are supported by their respective reinforcement layers. Thus unlike the single segment walls, the soil mass being filled and compacted is fully restrained laterally while the reinforced soil mass below the level of construction is not fully restrained. Thus for the lower panels, the yielding of the lateral soil boundary is possible and controlled only by the stiffness of the reinforcement, the connection method and the flexibility of the facing unit. Additionally, during the compaction process, the backfill to the propped panel, is subjected to soil 'locked-in' stresses due to the compaction forces which may increase the lateral earth pressures and inspite of the ability of the soil boundary to yield in the reinforced soil mass below, some locked-in stresses may develop. If the compaction forces are sufficiently high to be recorded in the lower layers, these stresses will increase the horizontal earth pressures. Additionally, with the removal of props of the panels most recently backfilled, the panel moves and in doing so drags and develops shear stresses along the horizontal soil surface, as shown in Fig. 7. It is suggested that these shear stresses will also cause an increase in lateral earth pressures in the lower panels.

For both the single and multi segmented wall methods of construction, the measured loads and strains along the reinforcement layers were not uniform, with peak loads and strains occurring fairly uniformly approximately 0.35m - 0.4m (0.22H - 0.24H) from the rear of the facing panels.

When the fill was at full height and the props removed, the measured strains along the bottom layer of reinforcement in the single segment walls were smaller than in the multi-segmented wall, along the top layers of reinforcement, while under the same conditions, the strains recorded in the single segment wall were larger than the multi-segmented wall. However, the load distribution was similar for single and multi-segmented walls for those conditions. This apparent contradiction is most probably due to the differences in magnitudes of 'locked-in' strains and strains induced by tensile loads.

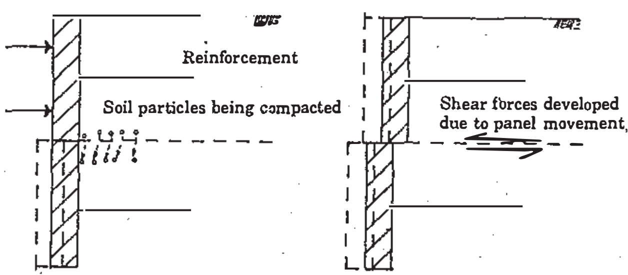

Fig. 7 Development of additional stresses in multi segmented walls

6 CONCLUSIONS

From the large scale experiments and the analysis carried out, the following conclusions may be drawn.

a. In single segment walls, when the fill is at full-height and before prop removal, the horizontal earth pressures in the lower half of the wall reduces to less than the at-rest pressures. When the reinforcements were attached and the props removed, the soil boundary was allowed to displace more freely, and the horizontal earth pressures to values reduced to values lower than the active pressures.

b. In the multi segmented walls, during the compaction process, the horizontal earth pressure on the unsupported panels is increased, as the boundary is still restrained by the stiffness of the reinforcements and does not move sufficiently to release the stresses.

c. Under similar conditions, the horizontal earth pressures generated on the rear of the facing of the multi-segmented walls were larger than the horizontal earth pressures at the rear of single segment wall. The ratio is approximately 1.5:1. These high stresses are caused by among other things the shear stresses developed between the horizontal soil surfaces when the props are removed.

d. When the fill was at full-height and all the props are removed, the load and strain distributions along the reinforcements are not uniform with peak values occurring approximately 0.22H - 0.24H from the rear of the facing panels.

e. The strain distribution in the lower reinforcement layer was larger in the multi segmented as compared to the single segment wall. However the reverse was true for the top layer of reinforcement.

f. The load distribution was similar for both construction methods for the conditions tested.This shows the difference of moduli that could develop in soil reinforcements, with different methods of construction.

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