Earth Reinforcement, Ochiai, Yasufuku & Omine (eds) © 1996 Balkema, Rotterdam. ISBN 90 5410 833 9

# The effect of compaction on model fabric reinforced brick faced earth retaining walls

T.W.Cousens
*University of Leeds, UK*

M. Isabel M. Pinto
*University of Coimbra, Portugal*

ABSTRACT: Many theoretical and experimental studies of earth retaining walls have been concerned with backfills placed against the wall and not compacted in situ and therefore they do not represent the constructional techniques of backfilling in actual retaining walls. Compaction has sometimes been accompanied by unexpected excessive movement of the retaining structures, being the horizontal earth pressure developed by soil compaction, blamed for this.

The effect of compaction was studied on walls which were built, backfilled and then surcharged. Backfilling was done in layers, each layer being carefully placed and compacted. The results of the present investigation show that for both unreinforced and reinforced earth retaining walls the behaviour on backfilling is complex and also completely different from that on surcharging. On backfilling, most of the variation of the quantities measured is due to compaction rather than to placement of the sand layers, this effect being especially evident in the wall deflection.

## 1 - INTRODUCTION

Sometimes earth retaining walls show unexpected excessive deflections during compaction. However, it is recognised that when compaction takes place both the magnitude and distribution of the horizontal earth pressure behind retaining structures are not those predicted by classical theories as higher pressures are induced by compaction adjacent to the walls and upon the removal of the compaction device residual pressures are still present. This effect was reported by investigators who studied the effect of compaction on reinforced earth retaining walls (Thamm, Krieger and Krieger, 1990) and on traditional unreinforced walls (Aggour and Brown, 1974, Butcher and Marsland, 1989, Cerder, Pocock and Murray, 1977, Ingold, 1979, Sowers et al, 1957), and was also detected in the present investigation.

The effect of compaction has been relatively well studied on traditional unreinforced walls. However, this is not the case of reinforced earth retaining walls where very little investigation has so far been undertaken. In most of the experimental studies backfilling is done by the popular raining technique, although in real constructions a compaction device is used.

The results described in this paper were obtained from a serie of tests carried out on model brick-faced walls reinforced with short length reinforcement sheets extended horizontally from the face of the wall into the backfill. Some unreinforced walls were also tested. The walls were 30 cm high, and two different lengths of reinforcement were tested (8 and 12 cm) in combination with three different spacings (2, 3 and 4 brick courses). Different foundation ground qualities were simulated. All the walls were built, backfilled and then surcharged.

The surcharge was applied by a water pressure bag laid over the full area of the top surface of the backfill. The popular raining technique used for backfiring in most laboratory investigations was not adopted in the study of model fabric reinforced brick faced earth retaining walls in order to represent more closely the backfilling of actual constructions. Backfilling was done in layers, each layer being carefully placed and compacted. The required soil density of 16.3 $kN/m^3$ was achieved by placing the sand in 30 mm layers, each layer being compacted by a compressed air driven plate.

The sand was predominantly of medium grain size, with limiting densities of 14.4 $kN/m^3$ and 16.8 $kN/m^3$. It showed angles of friction of $40^0$ (peak) and $35^0$ (constant volume), when tested over a normal stress range of 0 to 30 $kN/m^2$. The peak angle of friction between the sand and the brick was $37^0$.

## 2 - RESULTS

The results of the present investigation showed that for both unreinforced and reinforced earth retaining walls the behaviour on backfilling is complex and also completely different from that on surcharging. On backfilling two readings were always taken for each height of backfill, one after the placement of a layer of sand and another immediately after compaction. Therefore the second reading is of residual values remaining after compaction device has been removed. On backfilling, most of the variation of the quantities measured is due to compaction rather than to placement of the sand layers.

2.1 - Wall deflection

The behaviour of both unreinforced and reinforced walls is similar during backfilling where very small deflections are developed due to placement of a single layer of soil and most of the movement suffered by the wall is generated during compaction.

During backfilling two deflection values were measured at each level of backfill, one just after the placement of a layer of sand (the lower value) and another after compaction (the upper value).

For unreinforced walls the increments of movement due to compaction of a layer of soil increases as the height of the backfill approaches its maximum (Fig. 2) whereas for reinforced walls each increment seems to be about the same (Fig. 3).

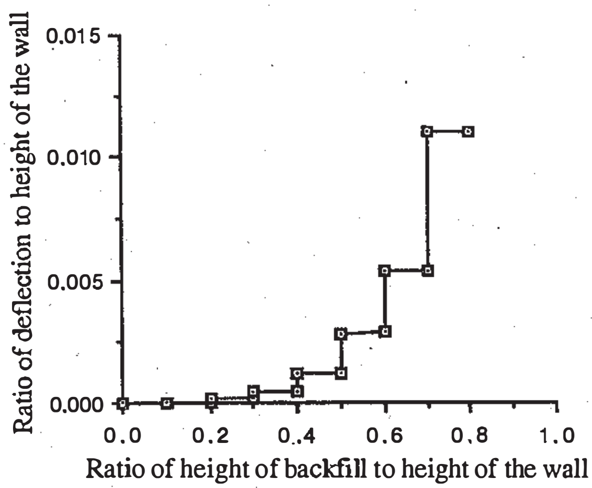


Fig. 1 - Horizontal movement on backfiling (unreinforced wall with a rigid foundation ground)

Comparisons between deflection rates during the backfilling stage with those during surcharging but before serviceability limit were made. The results showed that they are always of much greater magnitude during backfilling than during surcharging and that this difference is accentuated as the foundation ground decreases its quality. For walls built on poor foundation grounds (simulated in this investigation by walls built on a 50 mm layer of sand of the same density as the rest of the backfill and with a foundation of the same width as the wall) it was found that for the same increment of load the measured wall's deflection rate on backfilling reaches values as high as 15 times those on surcharging (as it can be seen from Fig. 3).

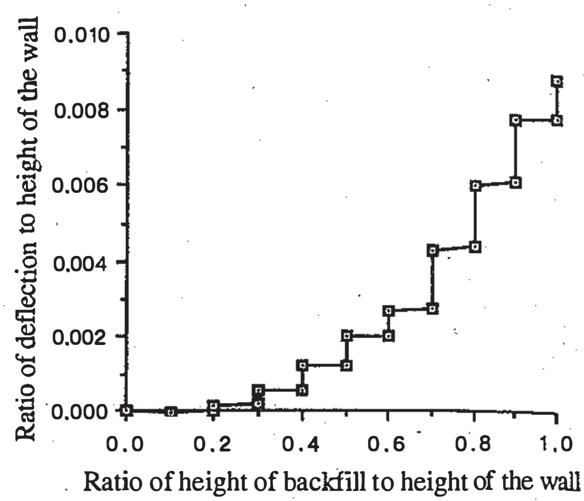


Fig. 2 - Horizontal movement on backfiling (reinforced wall with a rigid foundation ground)

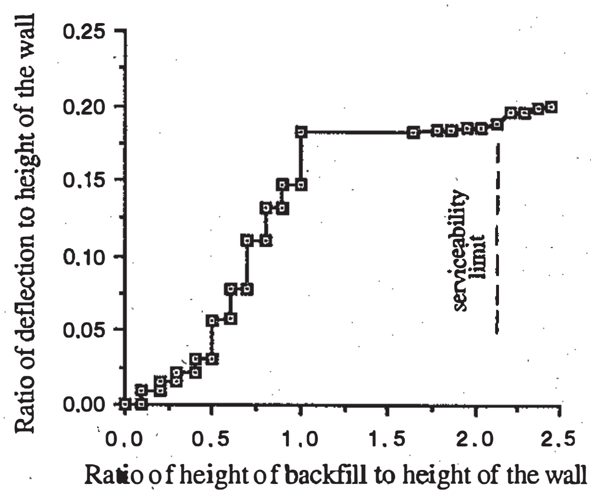


Fig. 3 - Horizontal movement (reinforced wall with a poor foundation ground)

2.2 - Horizontal earth pressure

Different behaviour on backfilling and surcharging is, again, noticeable. The variation of the horizontal earth pressure is complex, showing always a significant increase in the vicinity of the layer where compaction takes place. At this level the residual horizontal pressure reaches very high values, close to those corresponding to the passive state (see Fig. 4 where passive and at rest pressures were predicted for an angle of wall friction of 37$^0$ which was value measured between the sand and the brick). With further backfilling it tends to the active state on unreinforced walls and to values slightly higher than the at rest state on reinforced walls.

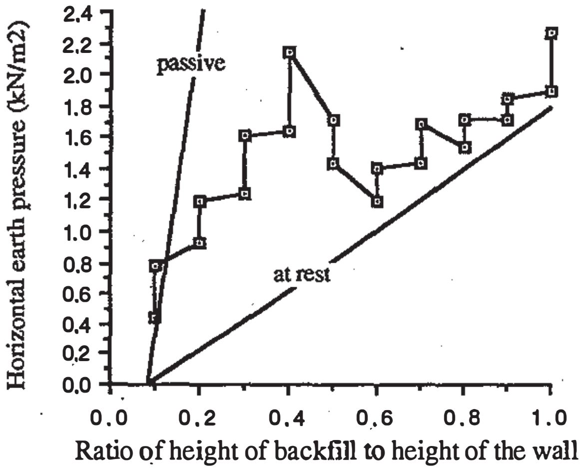


Fig. 4 - Horizontal earth pressure on backfilling

The effect of compaction is of increasing the horizontal pressure in the vicinity of the layer where compaction takes place, this effect being rapidly reduced on deeper layers. The ratio of horizontal to vertical stresses is initially high and as backfilling progresses it decreases tending to a constant value as the effect of compaction becomes negligible (Fig. 5).

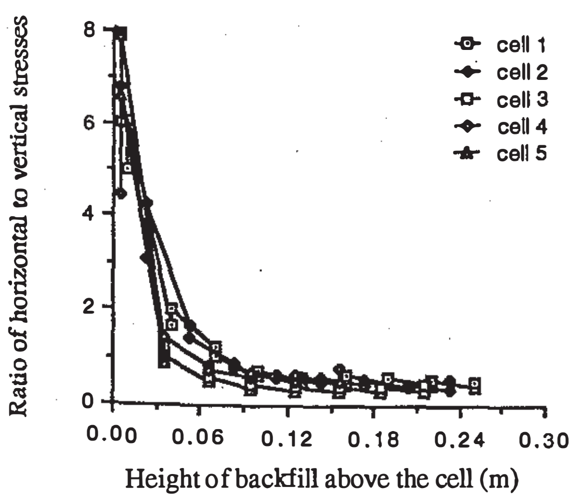


Fig. 5 - Ratio of horizontal to vertical stresses on backfilling

2.3 - Reinforcement

The behaviour of the reinforcement on backfilling can be divided into two phases. An initial phase (for no more than 2 or 3 sand layers placement) where the reinforcement exhibit a decrease of tension and a second phase where the trend is of increasing tension (see Fig. 6 as an example). Although both the placement and compaction produce the same effect, i. e. decrease of tension on the reinforcement layers closer to the sand layer where compaction takes place and increase of tension on deeper layers, that effect is greatly accentuated by the compaction process.

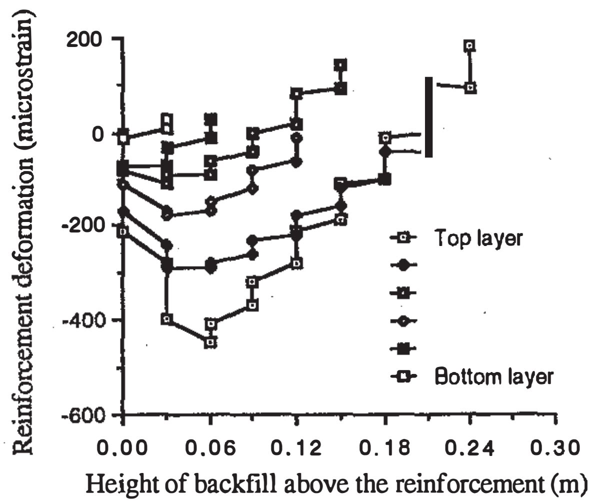


Fig. 6 - Reinforcement deformation on backfilling

3 - DISCUSSION

The effect of compaction described was generally similar for all tests despite the different foundation conditions and seems to be in good agreement with the findings of other researchers.

Thamm, Krieger and Krieger (1990) tested a full-scale geotextile reinforced earth retaining wall with a fabric face and reported that the horizontal earth pressure developed temporary maximum values caused by compaction of the soil layers and that the pressures decreased with time and further construction.

On traditional unreinforced walls using compaction techniques on backfilling, Sowers et al (1957) measured residual pressures exceeding the at rest state which were several times greater than those on the same soils loosely placed. Aggour and Brown (1974) reported that compaction changes the distribution of the horizontal earth pressures by increasing it in the upper half of the wall and reducing it in the lower half.

According to Sowers et al (1957) the excessive deflections of the earth retaining walls (where the compaction techniques are used) are due to high horizontal pressures resulting from an additional vertical load. The authors suggest that during compaction an additional vertical pressure is applied over a limited area, and this generates an additional horizontal pressure immediately beneath the compaction device. This suggestion seems to fit the data obtained in this investigation where the movement of the wall is shown to increase due to compaction and increments of the normal stress on the base of the tank due to compaction process were also measured (see Fig. 7).

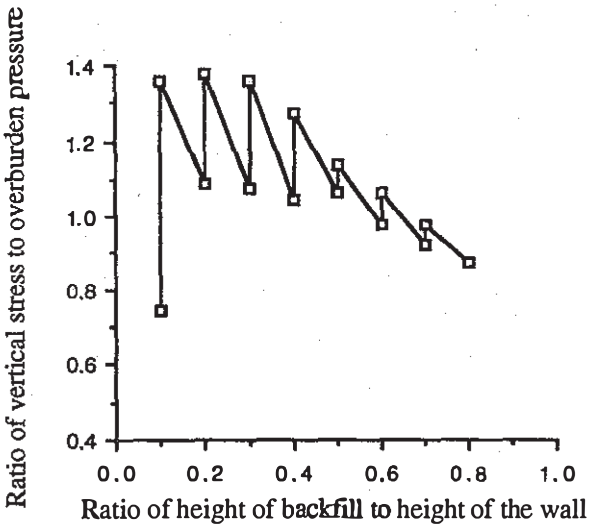


Fig. 7 - Variation of the vertical stresses on backfiling

This explanation seems to be reasonable as it is well known how much the horizontal earth pressure is affected by the vertical stress. Sowers et al (1957) reported that the horizontal pressure did not change appreciably with time after the compaction work was completed, and presented an explanation for that, based on friction developed between the soil and the structure. According to Sowers et al, "during compaction the soil moves downwards against the structure and when compaction pressure is released the upward movement is restricted by friction, making the full expansion impossible ".

According to Sowers et al (1957) and to Carder, Pocock and Murray (1977) the high pressures developed by compaction depend on at least three factors:

1- the dimensions of the compacting device employed and the pressure produced;

2- the deflection of the retaining structure;

3- the properties of the soil.

While the first factor defines the additional pressure generated during compaction and the volume of the backfill affected, the second determines the difference between that pressure and the residual pressure. The last factor is of importance in any problem involving soil, however, with respect to the effect of compaction the situation is more complex as the properties of the soil are themselves affected during compaction process.

During compaction a dynamic loading system is applied to the soil. Therefore, for a better understanding of the effect of compaction on the behaviour of the earth retaining walls, the response of the soil mass to vibrations must be considered. This includes the changes in the soil's physical parameters caused by dynamic effects. Kézdi and Réthâti (1988) explained that the coefficient of friction was among the properties substantially affected by vibrations: "the vibrations generated during compaction are transmitted to the soil particles which are displayed from their original position and start vibrating owing to their inertia"; the number of contact points between vibrating particles are temporary reduced and consequently $\phi$ is also reduced. The effect of vibrations on the angle of friction in sand was studied by Barkan (1962) who found that $\phi$ decreased when either the amplitude or the frequency of the vibrations increased, suffering even a drop if the frequency was increased beyond a certain critical value (see Fig. 8).

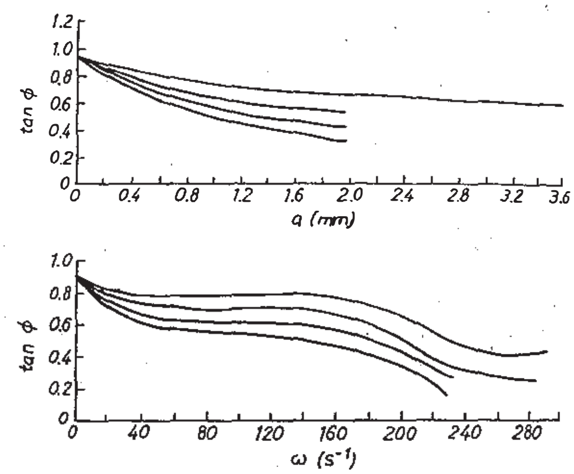


Fig. 8 - Angle of friction of a sand vs frequency and amplitude of vibration (Barkan, 1962)

The magnitude of the horizontal earth pressure increases as the angle of friction decreases. Therefore although the reduction of $\phi$ may not have a direct effect on the residual pressure it is likely to have a great contribution for the development of higher horizontal pressures during compaction and consequently for the high deflection of the wall.

According to D'Appolonia, Whitman and D'Appolonia (1969) , there is a zone of backfill poorly compacted after compaction and before further backfilling due to a loose settling of the soil particles when the vibration stops. This effect called "overvibration" leads to reduced angles of friction and consequently to higher residual horizontal pressure in the vicinity of the layer where compaction takes place.

Therefore the two factors described above may contribute to the different behaviour developed during compaction processes: additional vertical pressure and reduction of the angle of friction of the soil both during compaction and after that.

The residual horizontal earth pressure depends not only on the pressure developed during compaction but also on the deflection suffered by the retaining structure and on the soil- structure friction. In the current investigation the horizontal movement of traditional unreinforced walls seems high enough to allow the development of horizontal pressures close to those corresponding to the active state while in reinforced walls the movement is small enough to maintain that pressure slightly higher than that corresponding to the at rest state. Movements varying from about H/120 to H/200 (H being the height of the wall) were required to take the soil to the active state. Although these values are higher than those reported by Carder, Pocock and Murray, 1977 (H/1000) and Butcher and Marsland, 1984 (H/2000) they are of the same order of those reported by Terzaghi.

The phenomenon of reduction in tension of the reinforcement during backfilling is not reported in the literature. However, Boden, Irwin and Pocock (1977) recommended that the compaction process should be started "furthest from the wall and working towards the face to enable the ends of the strips to be held firmly in position" to ensure the reinforcement is anchored. This recommendation seems to suggest that a reduction in tension is possible when compaction starts from the wall's face, which was the case of the present experimental programme. During compaction of a layer of sand the soil particles in the neighbourhood move towards the wall this action being transmitted to the nearby reinforcement layers, and it might be that because the end of the reinforcement is not securely fixed in the present investigation, a reduction in tension is possible.

## 4 - CONCLUSIONS

Changes of wall deflections and horizontal earth pressures are of much higher magnitude on backfilling than on surcharging for equivalent increments of backfill. It was found that for the same increment of load the measured normal stresses on backfilling is roughly 1.2 to 2 times the stress on surcharging and the wall's deflection rate on backfilling reaches values as high as 15 times those on surcharging. The horizontal earth pressure reaches very high values, close to those corresponding to the passive state. Two factors may contribute to the different behaviour developed during compaction processes: additional vertical pressure and reduction of the angle of friction of the soil both during compaction and after that.

The reinforcement deformation on backfilling is very complex, and of a completely different type, with reduction followed by increasing of tension.

The effect of compaction has been relatively well studied on traditional unreinforced walls where analytical methods which consider the effect of compaction on the distribution and magnitude of the horizontal earth pressure have been proposed (Aggour and Brown, 1974 and Ingold, 1979). This is not the case for reinforced earth retaining walls where very little investigation has so far been undertaken on such matters. Some practical construction techniques for these walls have however been proposed in order to avoid or to minimise the unwanted effects of compaction:

1- compact the backfill in the direction towards the wall (Boden, Irwin and Pocock, 1977);

2- use a lighter compacting device within 1m (Boden, Irwin and Pocock, 1977) or 2m (Smith, 1977) from the wall, to protect the face and to reduce the development of the horizontal earth pressure and consequently the deflection of the wall.


## ACKNOWLEDGEMENTS

Thanks to the Commission of the European Communities and Junta Nacional de Investigação Científica e Tecnológica (JNICT) for financial support and to the Department of Civil Engineering of the University of Leeds, in U.K., and of the University of Coimbra, in Portugal, that made this research project possible.


## REFERENCES


Aggour, M. S. & Brown, C. B., 1974. The prediction of earth pressure on retaining walls due to compaction. *Geotechnique* 24: 489-502.

Barkan, D. D., 1962. Dynamics of bases and foundations. *McGraw - Hill.* New York, (referenced by Kézdi and Réthátí in 1988).

Boden, J. B., Irwin, M. J. & Pocock, R. G., 1977. Construction of experimental reinforced earth walls at the Transport and Road Research Laboratory. *TRRL SR 457*. Edinburgh: 162-194.

Butcher, A. P. & Marsland, A., 1989. Measurements of lateral earth pressure on bridge abutments. *Proceedings of the Conference on Geotechnical Instrumentation in Civil Engineering Projects.* The Institution of Civil Engineers, Nottingham: 341-356.

Carder, D. R., Pocock, R. G. & Murray, R. T., 1977. Experimental retaining wall facility - lateral stress measurements with sand backfill. *TRRL LR 766.*

D'Appolonia, D. J., Whitman, R. V. & D'Appolonia, E. D., 1969. Sand compaction with vibratory rollers. *Journal of the Soil Mechanics and Foundation Division, ASCE* 95: 263-284.

Ingold, T. S., 1979. The effects of compaction on retaining walls. *Geotechnique* 29: 265-283.

Kézdi, A. & Réthâti, L., 1988. *Handbook of soil mechanics*. 3, Amsterdam: Elsevier Science Publishers.

Pinto, M. Isabel M., 1992. Model studies of fabric-reinforced brick-faced earth-retaining walls. *PhD Thesis*. Leeds University.

Smith, G. N., 1977, Summary of Section II (Construction experience) discussion. *TRRL SR 457*: 243-245.

Sowers, G. F., Robb, A. D., Mullis, C. H. & Glenn, A. J., 1957. The residual lateral pressures produced by compacting soils. *Proceedings of the fourth International Conference on Soil Mechanics and Foundation Engineering* 2: 243-247.

Thamm, B. R., Krieger, B. & Krieger, J., 1990. Full-scale test on a geotextile reinforced retaining structure. *Proceedings of the 4th International Conference on Geotextiles, Geomembranes and Related Products*. The Hague: 3-8.