Lateral Deformation Characteristics of Coir Geomat Reinforced Vertical Embankments

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Abstract

For the design of internally stabilised reinforced earth walls, the lateral deformation is not considered as a design criterion and therefore, the designer would not know the performance of the wall with regard to its aesthetic appearance during its service life. Therefore, it is imperative that the designer limits the lateral deformation of reinforced earth walls under service loads. In addition to the durability considerations, suitability of application of coir geomats as the reinforcing material in a vertical embankment requires an investigation of its lateral deformation characteristics as well. In this study, the lateral deformation characteristics of a model vertical embankment (500 mm high, 700 mm long) reinforced with coir geomats of length 605 mm placed at a vertical spacing of 100 mm are compared with the lateral deformation characteristics of the same model embankment reinforced with needle punched geotextiles. The loading was carried out up to a maximum surcharge pressure of 250 kPa under natural moisture content and soaked conditions.

The results show that the lateral deformation exhibited by the coir geomat reinforced embankment is comparatively less than that exhibited by the geotextile reinforced embankment corresponding to the same fraction of the design surcharge pressure which would develop the maximum tensile strength of the reinforcement, under the natural and soaked moisture conditions.

Keywords: Geo-reinforcement, coir geomats, vertical embankment, lateral deformation, model test

1. INTRODUCTION

Embankments built to support highways, buildings or to impound reservoirs are man-made structures that are constructed above the ground level by using a fill material or a combination of different fill materials. However, if the side slope is to be kept vertical it would be necessary to construct a retaining structure giving an external support to the vertical face or to design to withstand itself by introducing reinforcing materials such as geotextiles or geogrids in which case it is known as an internally stabilised vertical wall. When reinforcements are placed at a designed vertical spacing, each reinforcement will carry the force transferred by the soil within its tributary area (Sargunam and Kalyanasundaram, 1980) which can be calculated using Rankine's active earth pressure theory (Moore and Cole, 1977). It is also possible to use coir geomats as the reinforcing material as a cost effective solution to stabilise the vertical face of an embankment making use of its engineering properties, subject to satisfying the durability considerations of coir mats against degradation. This is in addition to carrying out thorough subsurface investigation to determine strength properties required for settlement evaluation and stability analyses (Leroueil and Rowe, 2001). While taking effective measures to ensure that the loss of tensile strength of reinforcement during the design life of the reinforced wall is kept within acceptable limits, it would be required to assess the performance of the wall with regard to its aesthetic appearance that could be affected due to excessive lateral deformation. Therefore, it is imperative that the designer limits the lateral deformation of reinforced earth walls under service loads. Chai et al, (2002) had conducted numerical analyses using finite element models and concluded that only when the embankment approaches to failure, the reinforcement has noticeable effect on lateral displacement of the soil.

2. MATERIALS AND METHODS

Initially less cohesive a suitable granular wall fill material was selected based on the particle size distribution, standard Proctor compaction and direct shear test results. The material thus selected gave the basic soil characteristics and shear strength properties as given in Table 1. The same soil was used for the construction of both vertical walls reinforced with either coir geo-mats or geotextiles. The coir geo-mat had a rib spacing of 25 mm and 17 mm along the machine and transverse directions respectively and a density of 650 g/m^2 where as the geotextile was of needle punched polyester (PET) type with a mass of 180 g/m^2. In order to design either the geo-mat or the geotextile reinforced vertical wall, wide-width tensile tests were carried out on geo-mats and geotextiles to evaluate the ultimate wide-width tensile strength under dry conditions in accordance with BS 6906:Part 1:1987. A summary of the wide-width tensile test results on coir geomat and geotextile reinforcement is given in Table 2.

Table 1. Wall fill soil data

Percentage coarse particles	*70*
Maximum dry density	*17.0 kN/m^3*
Optimum moisture content	*16.0 %*
Effective cohesion	*5 kPa*
Effective angle of internal friction	*31°*

The test vertical wall was constructed to have dimensions of 700 mm length, 605 mm width and 500 mm height. Either the coir geomat or geotextile reinforcement was placed well stretched at a vertical spacing of 100 mm to ensure that the force developed under the surcharge pressure of 250 kPa is below the maximum load obtained along the machine direction, which was evaluated based on the design procedures given by Koerner (1998).

Table 2. Summary of wide-width tensile test results of coir geomat and geotextiles

	Coir geomat		*Geotextile*	
	Machine direction	*Transverse direction*	*Machine direction*	*Transverse direction*
Elastic Limit (load) (kN/m)	*5.76*	*5.11*	*8.01*	*5.39*
Elastic Limit (Strain) (%)	*20.70*	*16.30*	*33.00*	*26.80*
Breaking Load (kN/m)	*7.45*	*8.67*	*11.14*	*8.90*
Maximum Load (kN/m)	*7.45*	*8.67*	*12.87*	*11.10*
Strain at Maximum Load (%)	*36.20*	*34.80*	*58.00*	*56.80*
Offset strain (%)	*2.14*	*3.14*	*2.60*	*4.80*
Offset Modulus (kN/m)	*34.62*	*40.97*	*26.64*	*24.52*

The stretching of the coir geomat or geotextile reinforcement was ensured by restraining the reinforcement at the front of the wall and rolling the material around a straight pole which was kept pulled towards the back of the wall fill until the soil layer was compacted. This practice has also been recommended by Day et al., (1995) in their study on field behavior of an instrumented geogrid soil reinforced wall. The soil was compacted to achieve a density of 95% of standard Proctor density at the corresponding water content of the dry side of the compaction curve and both types of reinforcement was wrapped around at the front end and anchored into the upper soil layer. In the case of geo-mat reinforcement, a piece of geotextile was placed behind the mat to prevent soil from falling through the openings of the mat. In order to ensure stability of side walls, an embankment having side slopes of 2H:1V was constructed using the same soil and at the same density. The front and cross-sectional views of the vertical wall configuration are given in Figure 1.

In the first stage of the experiment, coir geomats were used as the reinforcing material. A rigid steel plate was fabricated to apply the surcharge pressure to the vertical wall. Dial gauges were setup along the central axis of the wall at mid-height of each of the 5 soil layers to observe the lateral deformation of each soil layer. Therefore, the dial gauges identified from gauge A to gauge E were placed at depths from 450 mm to 50 mm at a spacing of 100 mm.

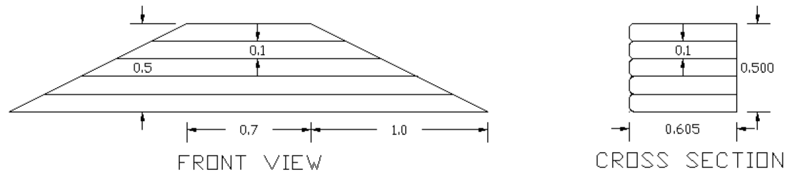

Figure1. Front and end view of the model vertical wall

The arrangement of the test set up is given in Figure 2 and Figure 3 for geo-mat and geotextile reinforced walls respectively. Then the plate was gradually loaded up to 5 tons which produced a contact surcharge pressure of 114 kPa. The pressure applied was unloaded and the lateral deformation of the wall as well as the vertical movement of the plate was monitored throughout the loading and unloading sequences. In the next stage of the experiment, in order to simulate wet conditions, the wall fill was allowed to soak for more than 48 hours ensuring that no surface soil eroded away. The loading was again carried out under wet conditions up to the applied load of 10 tons and then it was slowly unloaded.

Figure 2. Arrangement of test set up for geo-mat reinforced wall

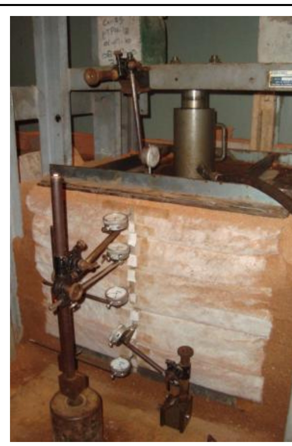

Figure 3. Arrangement of test set up for geotextile reinforced wall

3. RESULTS

3.1 Tests done at natural moisture content

The pressure-displacement relationships for the coir geomat reinforced wall during the loading-unloading and reloading-unloading stages of the experiment are given Figure 4.

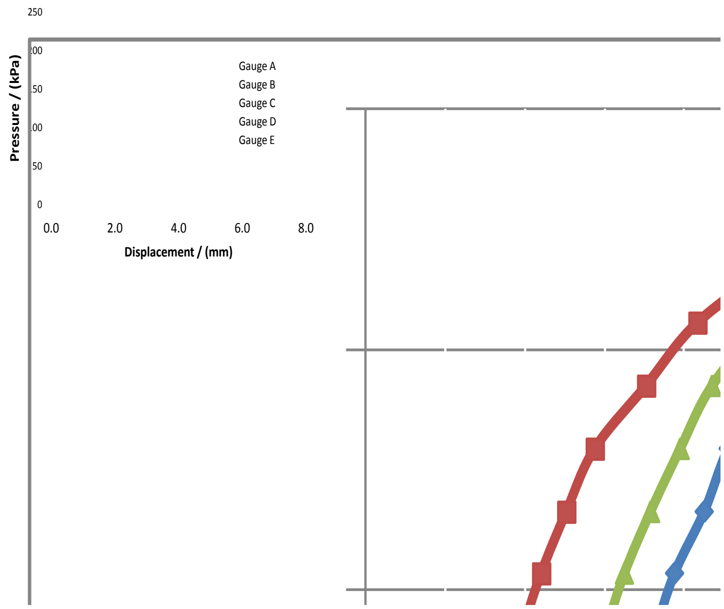

Figure 4. Pressure-Displacement relationships of coir geomat reinforced wall at natural moisture content

Figure 4 shows that the two bottommost soil layers did not undergo lateral deformation comparable with that of soil layers at top at half the design surcharge pressure. It also shows that a greater percentage of the deformation is plastic deformation and hardly any elastic rebound occurred when unloaded from half the design surcharge pressure. A visual presentation of the profile of the face of the wall along the central axis during the loading stage which continued up to half the design load monitored at more or less equal intervals of surcharge loading is given in Figure 5 and the same during the reloading stage up to the design surcharge pressure is given in Figure 6. Both figures show the comparatively less development of lateral deformation at the bottom which is in conformity of the observations made by Tan Swan Beng et al., (1982) on the first reinforced earth retaining wall in South East Asia (Singapore). However, upon reloading all the soil layers showed comparable lateral deformation.

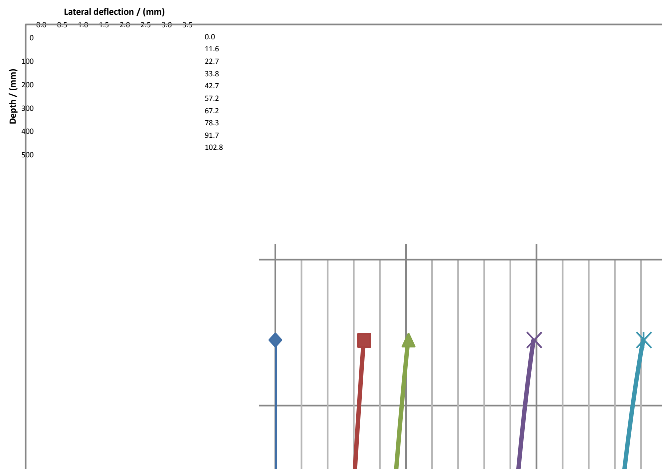

Figure 5. Vertical profile of coir geomat reinforced wall loaded up to half the design surcharge at natural moisture content

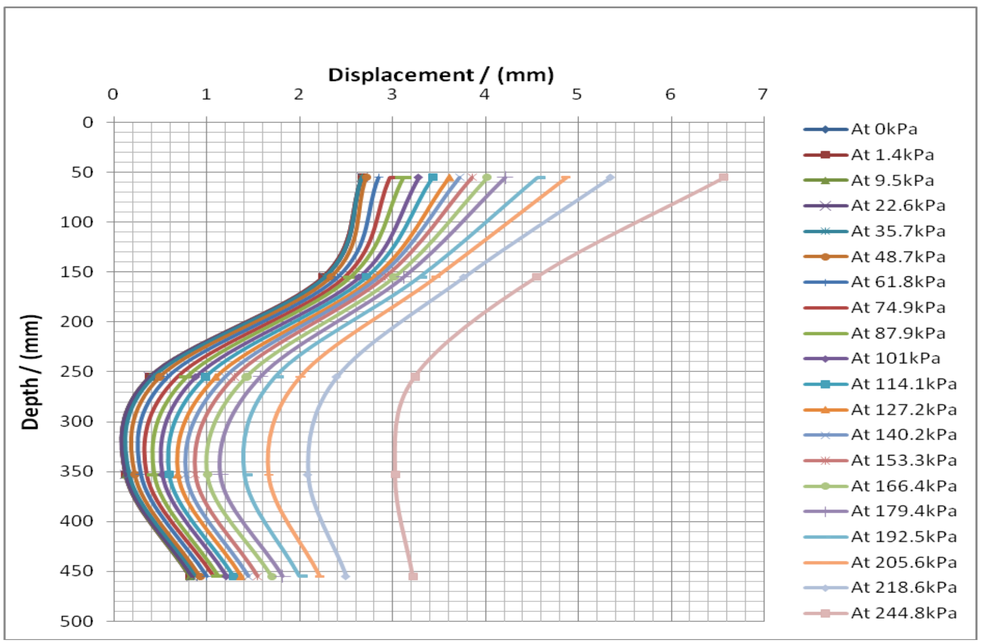

Figure 6. Vertical profile of coir geomat reinforced wall during the reloading stage at natural moisture content

Figure 7 gives the pressure displacement relationships of a similar series of tests carried out on a vertical wall reinforced with geotextiles during the loading-unloading and reloading-unloading stages. The observations are almost similar to those in the case of coir geomat reinforced wall showing very insignificant elastic recovery during unloading stage. Further, it is observed that the elastic recovery that occurred during the initial unloading stage deformed back at very early stages of the reloading stage. The progressive changes to the initial vertical profile of the face of the wall during the initial loading stage and during the reloading stage are given in Figure 8 and Figure 9 respectively.

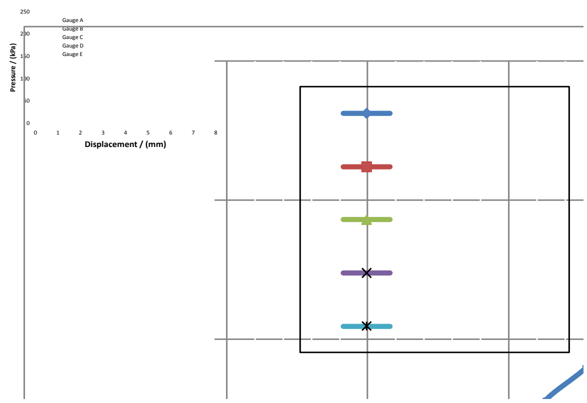

Figure 7. Pressure-Displacement relationships of geotextile reinforced wall at natural moisture content

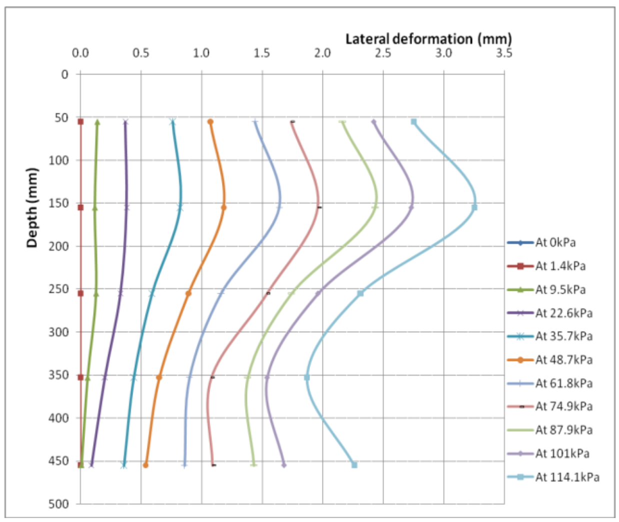

Figure 8. Vertical profile of geotextile reinforced wall loaded up to half the design surcharge at natural moisture content

It is noted that direct comparison of deflection of coir reinforced and geotextiles reinforced walls cannot be made disregarding the effects due to the differences of the ultimate load carrying capacity of the reinforcing elements as determined using the wide width tensile tests. As it is possible to back calculate the allowable surcharge pressure corresponding to the vertical spacing of the reinforcing material and the wall fill soil properties a comparison of the load deflection behaviour of the geomat and geotextiles reinforced walls can be made based on the lateral deflection observed under a specific fraction of the allowable surcharge pressure. For the materials used in this experimental study, the allowable surcharge pressure of coir geomat reinforced wall and geotextiles reinforced wall is 190.7 kPa and 293.6 kPa respectively, assigning a value of 1.0 for all the reduction factors and the global factor of safety.

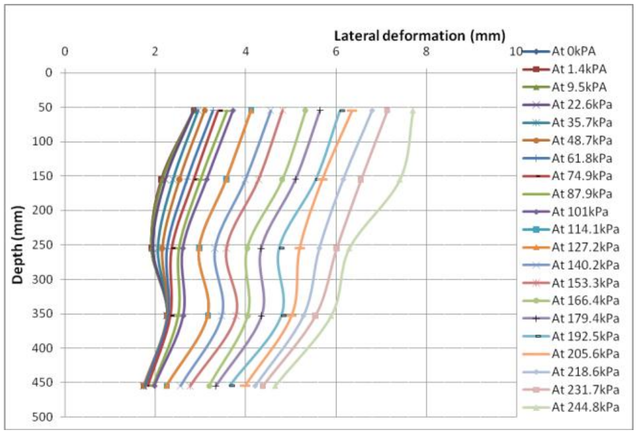

Figure 9. Vertical profile of geotextile reinforced wall during the reloading stage at natural moisture content

This comparison is done on the lateral deflection observed at the top layer of the wall which experienced the maximum deflection (Figure 9). Figure 10 gives the direct comparison of the lateral deflection ratio and the surcharge pressure ratio for the two identical walls reinforced with either coir geomats or geotextiles. It is evident from Figure 10 that, under natural moisture conditions, geotextile reinforced wall underwent greater lateral deflection corresponding to a particular applied load ratio. Therefore, under natural moisture conditions, the coir geomat reinforced wall had performed well in terms of serviceability conditions.

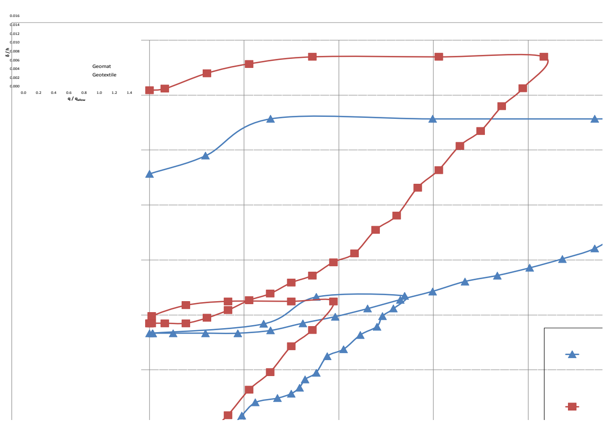

Figure 10. Deflection ratio corresponding with the load ratio under natural moisture content

3.2 Tests done under soaked condition

The pressure-lateral deformation relationships of the coir geomat reinforced wall when the loading is carried out under soaked condition are given in Figure 11. In comparison, the pressure-lateral deformation relationships of the geotextile reinforced wall under soaked conditions are given in Figure 12.

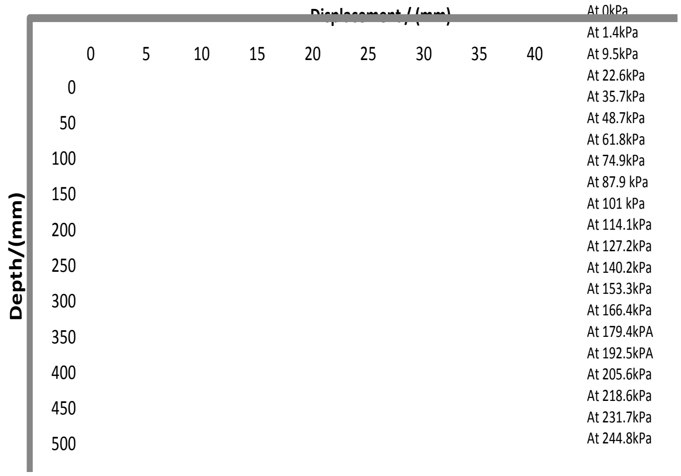

Figure 11. Vertical profile of coir geomat reinforced wall under soaked condition

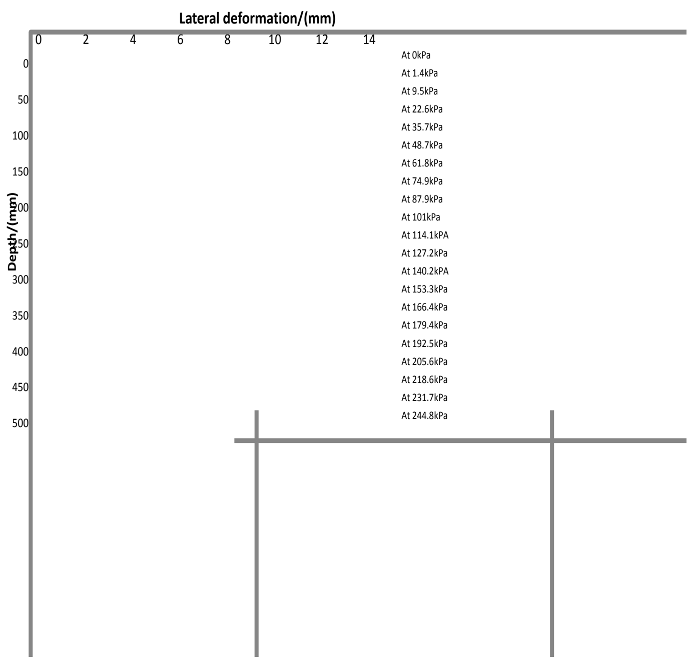

Figure 12. Vertical profile of geotextile reinforced wall under soaked condition

Figure 13 and Figure 14 give the pressure-displacement relationships for the loading tests done under soaked conditions for the geomat reinforced and geotextile reinforced walls respectively.

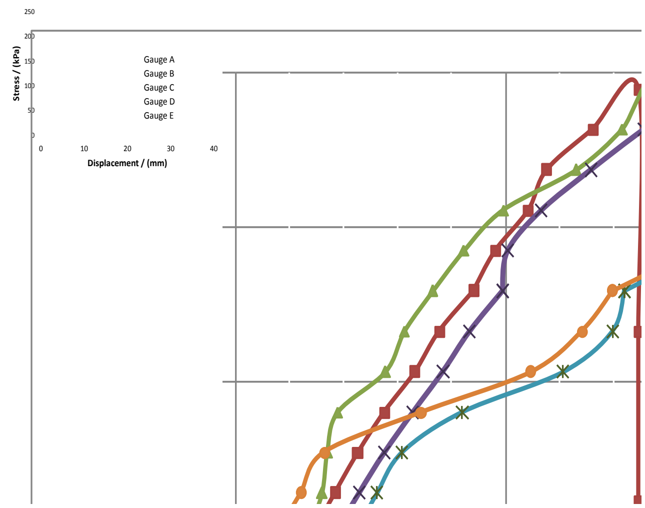

Figure 13. Pressure-Displacement relationships for the geomat reinforced wall under soaked condition

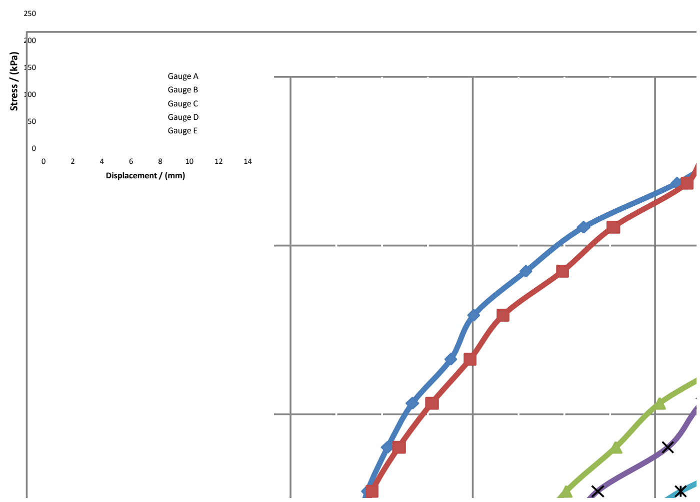

Figure 14. Pressure-Displacement relationships for the geotextile reinforced wall under soaked condition

The relative pressure deflection behaviour of the walls under soaked condition is given in Figure 15 which is drawn in a similar manner to that given in Figure 10. Under soaked condition too, the coir geomat reinforced wall had undergone less amount of lateral deflection.

Therefore, it is apparent that under natural moisture conditions and soaked conditions, coir geomat reinforced wall exhibited less amount of lateral deflection than that of geotextile reinforced wall. This behaviour is likely to have occurred due to the presence of passive resistance in front of the coir ribs running parallel to the wall at specific intervals. The geotextiles reinforced wall however, has no elements to develop passive resistance and has to solely rely on the shear resistance mobilized on both sides of the geotextile which are in contact with the wall fill soil.

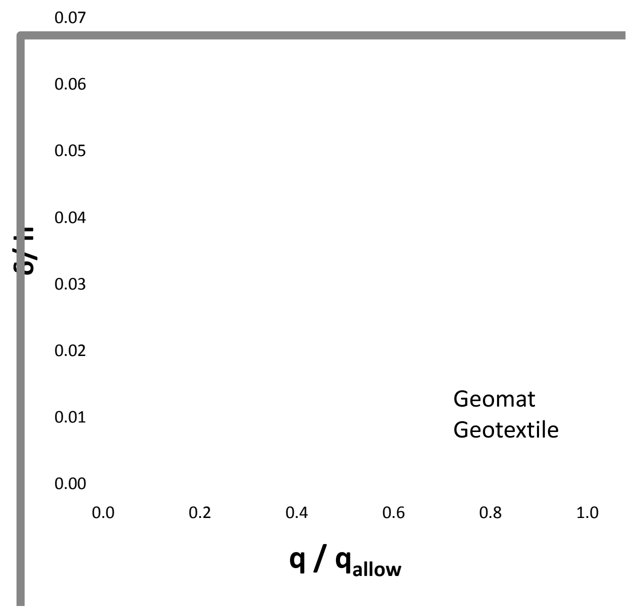

Figure 15. Deflection ratio corresponding with the load ratio under soaked condition

4. Concluding Remarks

Based on the laboratory experimental model study on the lateral deformation of coir geomat reinforced vertical embankment under natural moisture content and soaked conditions, the following conclusions can be made.

(1) The lateral deformation undergone during loading up to even half the design surcharge pressure was essentially consists of plastic deformation.

(2) Irrespective of whether the loading is applied under natural moisture content of the fill or soaked conditions, the coir geomat reinforced vertical wall showed less lateral deformation than that for geotextile reinforced wall, at the same fraction of the allowable surcharge pressure corresponding to each material.

5. References

BS 6906 : Part 1 : 1987; British Standards Institution.

Chai, J.C. and Zhu, H.H. (2002). Behavior of reinforced embankment over soft subsoil. Proc. of the Inter. Seminar on Practice and Advance in Geotechnical Engineering, Shanghai, China, pp. 71-83.

Day Robert W., “Discussion on Field behavior of instrumented geogrid soil reinforced wall”, Journal of Geotechnical and Geo Environmental Engineering, ASCE, 121, V.2, 1995, pp 222.

Koerner Robert M, (1998) “Designing with Geosynthetics”, Fourth edition, Prentice Hall, Englewood cliffs, New Jersey.

Leroueil S. and Rowe R.K., “Geotechnical and Geo environmental Hand book”, Kluwer Publications, USA. 2001.

Moore P. J. and Cole B.R, “Active Pressure observation on a model retaining wall”, Proceedings of Fifth Southeast Asian conference on Soil Engineering, Bangkok, 1977. pp 235-244.

Sargunam A. and Kalyanasundaram I. “Model Studies of Reinforced earth retaining walls”, Proceedings of Sixth Southeast Asian conference on Soil Engineering, Vol 1, Taipei, 1980. pp 563-577.

Tan Swan Beng, Pang Poh Yang and Yap Neng Chew, “Construction and Performance of a reinforced Earth retaining wall in Singapore”, Proceedings of Seventh Southeast Asian Geotechnical conference, 1982. pp 545- 555.