The 1st Regional Conference of Eng. Sci. NUCEJ Spatial ISSUE vol.11,No.3, 2008 pp 374-381

The Effect of Reinforcement Density on The Deflection of Reinforced Soil Retaining Wall

Dhiaadin Bahaadin Noory Zangana

MSc. Civil Engineering / Geotechniqu
Lecturer
Building and Construction Dept. College of Engineering University of Sulaimani

Abstract

This research involves the effect of both vertical and horizontal spacing, as well as the length of the reinforcing strips, on the structural behavior of a model reinforced soil retaining wall.

The tests were carried out on a small-scale laboratory model, in which uniform graded sand was used as a fill material. It was placed at a high dense state; raining technique was used for this purpose. The sand was reinforced with thin dipped Aluminum strips. The size of these reinforcing strips was chosen sufficient enough to prevent rupture mode of failure. The retaining wall was presented by a plastic transparent sheet. The results showed that the horizontal spacing is more significant parameter on deflection of the wall as compared to the vertical spacing of the reinforcing strips. The critical values of the horizontal and vertical spacing with respect to this research were 20 and 10 cm respectively. A short length of reinforcement proved to cause appreciable deflection of the wall, even under close horizontal and vertical spacing.

Keywords

Retaining wall, vertical spacing of reinforcing strips, horizontal spacing of reinforcing strips, length of reinforcing strips, deflection.

Symboles

H	Total height of retaining wall
S_v	Vertical spacing of reinforcing Strips.
S_h	Horizontal spacing of reinforcing Strips.
L	Length of the reinforcing strips

Introduction

Reinforced soil is defined as, a construction material composed of soil fill limited to cohesionnless free drainage materials, that is strong in compression but weak in tension, and the reinforcing strips, which are relatively high tensile strength materials, placed at stipulated spacing, and they supply the mass with the necessary tensions. Lastly the facing element, which is usually non structure element, acting as an outer membrane to prevent the soil from sloughing [5]. The soil and reinforcing strips will interact by means of friction resistance [8], and results into stable mass, that behaves monolithically and can be used as earth retention and load supporting structures.

Reinforced soil is really an attractive and retaining walls, bridge abutments, platform supporting structures, foundation slabs, under water quay and sea walls, dams, sedimentation basins and tunnel linings etc.

The applications of reinforced soil to soil retaining and load supporting structures have been studied on a theoretical and analytical basis. The basic assumptions and results of these studies have been checked and found to be realistic by constructing small scale models in the laboratory. Most of the studies that have been traced till now were concerning the modes of failure, seismic effect on the behavior of reinforced soil wall, suitability of materials for reinforcing strips as well as the effect of placement condition of fill materials. On the other hand, the works performed on full scale structures were concentrated on the stress measurement within the soil and stress distribution along the reinforcements. Lee et.al. [7] have performed several studies on small model of reinforced earth Walls, using thin aluminum ties their results indicated that Rankine or Columb theory is suitable for design purposes. Smith and Bransby [10] carried out series of tests on small models of reinforced wall using aluminum foils, they used typical radio graph system to monitor the failure surface , they found that angle of failure plane varies between 20 - 25 degrees with vertical. Brom [3] carried out small scale laboratory tests using fiber reinforcement; his results enabled development of design criteria. Al-Hussaini and Perry [1] tested a full scale experimental wall, the wall was reinforced with galvanized steel and loaded by static surcharge up to failure, they concluded that the lateral pressure at the end of construction were approximately equal to those predicated by Rankine theory for active condition. Richardson et. al. [9] constructed a prototype wall and applied various dynamic loads. They showed that the static design of reinforced soil structure is convenient for moderately intense seismic loading.

None of the published works had paid attention to study the effect of reinforcing strips spacing on the behavior of reinforced sandy soil retaining wall. It is therefore the task of this research is to highlight the behavior of reinforced sandy soil retaining wall, with various spacing and length of the reinforcing strips.

Materials And Experimental Works

Materials Soil

The soil used in the tests of this research was from Khasa river bed in Kirkuk, which is available in large quantities in the local area, and used in most of construction activities. Suitable amount of the soil was washed, and sieved on sieve No. 14 and 200, to have a suitable particle size, for better workability conditions. Sieve analysis was carried out on the soil to determine the grain size distribution of the soil particles, according to the British standard and B.S.I 1377 **[4],** it was found that the soil was granular uniformly graded sand with a unified soil classification system destination SW, with a uniformity coefficient Cu=2.2, a concavity coefficient Cc=l.l and D_{5o}=0.4. The specific gravity of the sand particles was found to be 2.66 **[4].** The maximum density of the sand was determined by means of compaction test **[4],** while the minimum density was found by jar test method. The upper and lower values of the density were 16.98 and 14.32 kN/m^3 respectively. The density of the sand was calibrated by sand raining method [6]. The sand was rained through a mesh 2.87 x 2.87 mm opening, using different heights of drop, which gave different values of placing densities. It was decide to use dense state through out the research with density of 15 kN/m^3 This was obtained by 40 cm height of raining which yielded a relative density of 70%. The angle of internal friction between the sand grains was 35 degrees at the proposed density, which was determined using direct shear test **[4]**

Reinforcing strips

The reinforcing strips used in the model of this research were dipped aluminum 1.0 mm thick, 20 mm wide. The breaking strength of the reinforcing strip was 135 N/mm^2. The angle of friction between the sand particles and the reinforcing strips was 25 degrees, determined by direct shear test
using 60 x 60 mm shear box. The lower part of the box was filled with a wooden block, covered with the reinforcement material, while the upper part of the box was filled with the sand placed at the proposed density. A linear relationship was observed between normal stress and shear stress.

Testing Apparatus

The plan and appropriate section of the testing apparatus of this research is shown in **Fig. (1)** and **Fig.** (2) below respectively.

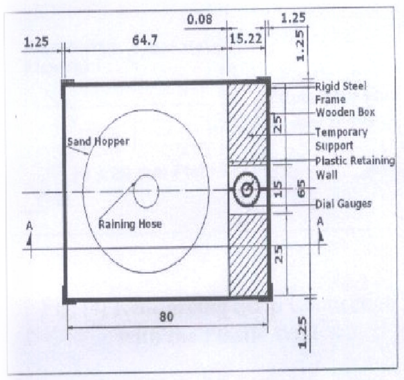


Fig. (1) Plan of the Model

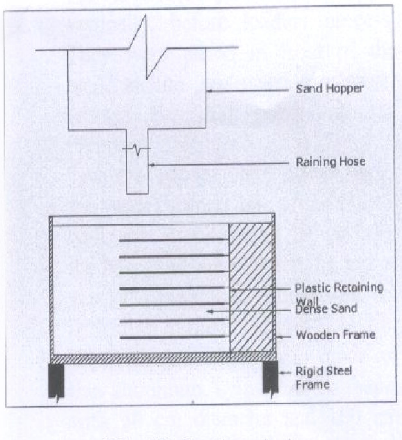


Fig. (2) Section A-A

The testing apparatus consists of:

1. A well stiffened wooden box of 800 x 650 x 450 mm internal dimensions, with 12.5 mm side thickness and 30 mm base thickness. The base contains two 20 x 20 mm square holes

provided with control gates for emptying the box.

2. A rigid steel frame, one meter high to support the wooden box.

3. The retaining wall model was selected to be transparent plastic sheet of 650 x 420 x 8 mm. The thickness of the wall model selected to give a measurable deflection with reasonable accuracy. The wall was simply supported at the base and let free at the top and side edges, to simulate the condition which is mainly faced in actual practice. The simply supported arrangement was made by inserting the plastic wall into 20 mm slot dragged across total width of the base of the wooden box at 15.22 cm from the right side of the wall.

Figure 3 below shows layout of the reinforcing strips location under different vertical and horizontal spacings used throughout the tests.

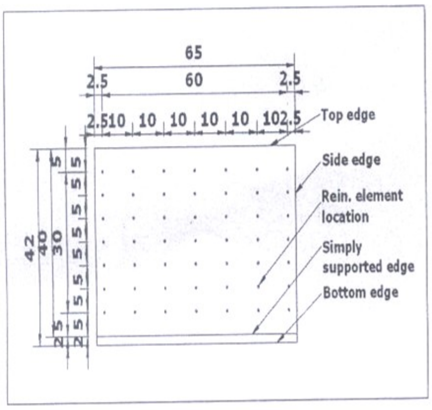
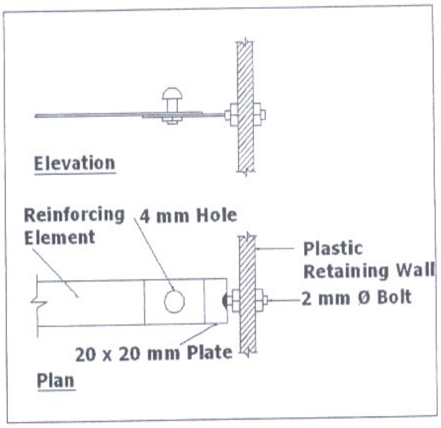


Fig (3)Layout of the Reinforcing Strip locations

4. Fourty nine number of 20 x 20 x 1 mm steel plates were attached to the plastic wall, at the required spacing, to act as connectors to the reinforcing strips. The reinforcing strips were bolted to the connecting plates through the holes provided for this purpose. A detail of connection arrangements is shown in Figure 4 below



Fig(5) Reinforcing Strip Connection with the plastic wall

5. Two temporary wooden supports of 25 x 15.22 x 40 cm dimension were used to hold the plastic wall vertically, before loading process. They were paced in front of the wall, at the box sides, to easily arrange the dial gauges at the proposed locations.

6. Two dial gauges were placed along the vertical center line of the plastic wall, one at spacing of 10 cm from the base, and the other at the top of vertical center line, to measure the deflection of the plastic wall.

7. Sand hopper which was made of thin aluminum, cylindrical in shape, with 50 cm diameter and 100 cm height. The outlet of the hopper was at the bottom and connected to the raining hose. The connection was flexible for easy control of sand raining. This was achieved by 80 mm dia. plastic pipe. 8. The raining hose was of sliding type. It consists of two aluminum pipes, one sliding inside the other, thus providing good control of raining height, A stainless steel mesh of 2.87 x 2.87 mm square opening was attached to the end of the hose, to control the rate of flowing sand. The size of the opening was selected to be sufficient for uniform flowing of sand during the filling process

Testing program

The main parameters concerned in this research were:

a. Effect of vertical spacing of the reinforcing strips.

b. Effect of horizontal spacing of the reinforcing strips.

c. Effect of length of the reinforcing strips.

For this purpose the testing program is divided into two groups, as follows:

1. Group I

One test was done on non-reinforced sandy soil retaining wall.

2. Group II

Twenty seven tests were done on reinforced sandy soil retaining wall, as follows:

a. Nine tests to show the effect of vertical spacing S_v, using L=25, 37.5 and 50 cm for different horizontal spacing Sh equal to 10,20 and 30 cm.

b. Nine tests to show the effect of horizontal spacing Sh, using S_v=5,10 and 15 cm for different length L equal to 25,37.5 and 50 cm.

c. Nine tests to show the effect of length L, using Sh=10,20 and 30 cm for different vertical spacing S_v equal to 5,10 and 15 cm.

While other parameters such as properties of the reinforcement, properties of the fill and placement density of the sand were kept constant.

Testing procedure

The testing procedure was done according to the following steps:

1. Placing the plastic wall model in its specified location by inserting it into 20 mm deep slot which was dragged in the wooden base, to act as simply supported of the bottom edge of the plastic wall.

2. Placing the two temporary wooden supports at their specified location in front of the plastic wall to hold it vertically.

3. Attaching the dial gauges at their proposed locations along the vertical center line of the plastic wall, and setting their reading to zero.

4. Placing the back fill soil by opening the lock of the raining hose. The height of falling was controlled by sliding the hose up and down, keeping a constant height of 40 cm above the sand surface. *Th.ic* **II'QC o'Ji'ilv** Hone with the aid of guide markers along the outer part of the hose. This height was chosen through the preliminary tests in order to obtain a high dense state of backfill, the raining hose was continuously moved forward and backward and in transverse directions. The sand was placed in layers of equal thickness, using marking lines on the interior sides of the box as a guide. When the level of the reinforcing strips was reached according to the testing program, leveling the sand surface was performed using a 2 mm thick steel strip across the full width of the box. Almost perfect leveling was needed to give a good contact between the reinforcing strips and the sand bed. This was achieved by gentle movement of the leveling strip forward and backward several times

5. Laying the reinforcing strips and connecting them to the supporting plates attached to the plastic wall.

6. Raising the temporary wooden supports, after completion of the backfill process, to release the plastic wall's free edges.

7. Recording reading of the dial gauges.

8. Opening the locks of the base holes control gates, at the end of the experiment, to discharge the sand from the box into a collection container. The collected sand was then transferred to the hopper to be reused in the next tests

Results And Discussion

Nature of the problem

The wall is assumed as an elastic plate under pure bending, subjected to transverse active pressure of the fill material, and resisting forces from the reinforcing strips. It is also assumed to be simply supported at the bottom edge, while free at the top edge and vertical sides. It is important to be mentioned that the amount of measured deflections is relatively small in comparison with the height of the wall. The maximum deflection is limited to half of the wall thickness. More than this value leads to an inaccurate results, due to development of the membrane stresses (i.e.normal stresses on the middle plan of the plate) **[2]**

Discussion of the results

Table 1 below shows the results of deflections, along the vertical center line of the wall, using different spacing and length of the reinforcements

Table (1) Results of Deflections

L (cm)	S_v (cm)	S_h (cm)	Δ at top of the wall (mm)	Δ at 10 cm from the base of the wall (mm)
50	5	10	0.30	0
		20	0.73	-0.007
		30	0.84	-0.009
	10	10	o.71	-0.01
		20	1.17	-0.02
		30	1.37	-0.05
	15	10	1.12	-0.07
		20	1.57	-0.09
		30	1.85	-0.12
37.5	5	10	0.49	-0.01
		20	0.77	-0.03
		30	1.23	-0.06
	10	10	0.97	-0.08
		20	1.55	-0.10
		30	2.17	-0.15
	15	10	1.17	-0.19
		20	2.0	-0.22
		30	2.59	-0.25
25	5	10	0.8	-0.03
		20	1.54	-0.05
		30	2.0	-0.08
	10	10	1.42	-0.10
		20	2.71	-0.15
		30	3.42	-0.20
	15	10	2.0	-0.25
		20	3.61	-0.30
		30	4.34	-0.35
None- reinforced			4.5	2

Figure 5 below shows typical distribution of deflection of the wall

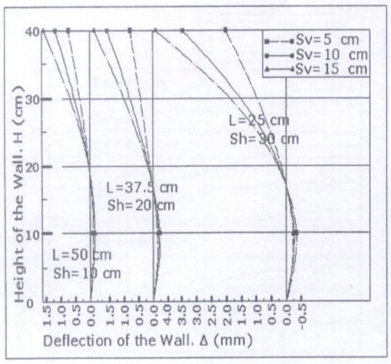


Fig. 5 Distribution of Deflection along the Vertical Center Line

It has been observed that the deflections follow the same trend in all the cases. The wall deflects in the same manner of a propped cantilever beam, subjected to triangular distribution load. Thus the maximum deflection occurred at the top part of the wall. This indicates that the strips in the lower half of the wall are more efficient in preventing the deflection than the upper strips, which means development of higher frictional resistance at the lower half of the wall. Also it has been observed that a rapid decrease in deflection occurs with depth. A point of zero deflection occurs at a depth slightly below the mid-height of the wall. Since the wall consists of a unit plate, and due to low efficiency of upper strips, it deflects in a manner that it moved outward in the upper part, while it showed an inward movement at the lower part. This revised deflection can be referred to different efficiency of the strips and rigidity of the wall.

Effect of vertical spacing S_v

It is found that for L=50 and 37.5 cm , the vertical spacing has slight effect on the deflection of the wall when Sh =10 and 20 cm, whilst when Sh=30 cm a significant effect is obtained. To clarify this, the variation of the maximum deflection with vertical spacing, at the top vertical center line of the wall is plotted in **Fig. 6** below

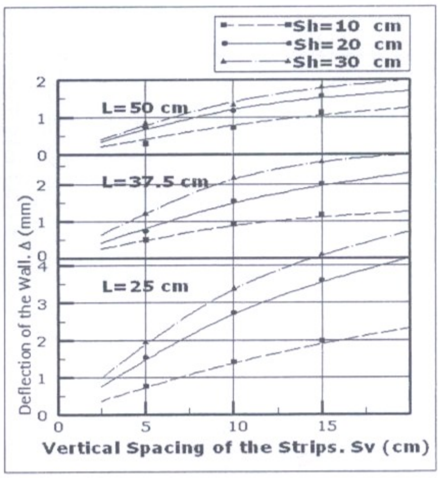


Fig6 variation of Maximum deflection with vertical spacing

The maximum deflection increased by increasing the vertical spacing. The rate of increase was found to be constant and gentle for all values of length of the strips. The deflection increased at a higher rate at the beginning, then decreased when S_v exceeded 10 cm. This is indicated by the difference in the slopes of the curve.

Effect of horizontal spacing Sh

Figure 7 below shows the variation of maximum deflection of the wall, with the horizontal spacing Sh at the top vertical center line of the wall.

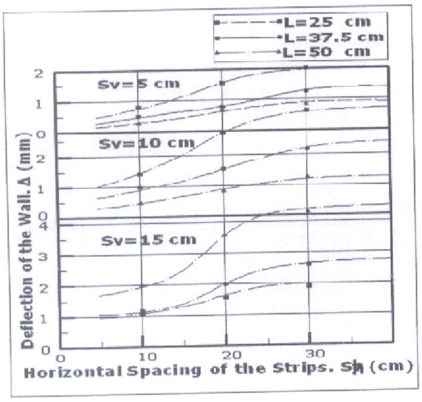


Fig 7 variation of Maximum deflection, with the Horizontal spacing

It is found that the rate of increase of maximum deflection when S_h was changed from 10 to 20 cm, is more than the change in the other range ,as illustrated by the slope of this portion of the curve.

Effect of length of the strips L:

It is noticed that the length of the reinforcing strips has a profound effect on the deflection of the wall, for any spacing of the strips. However the lower part of the wall is slightly affected by the length, while at the upper part, the deflection increased with decreasing length of the strips. Figure 8 below shows the variation of maximum deflection of the wall, with the length of the strips, at the vertical center line of the wall.

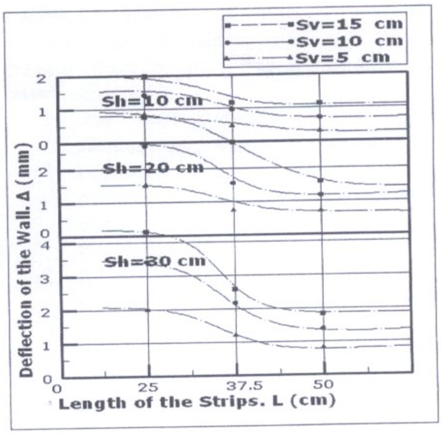


Fig 8 variation of maximum deflection with the length of the strips

It is observed that the maximum deflection decreases with increasing length of the strips. The relation is non-linear, where the deflection decreases at different rates. The greatest rate was found when the length was changed from 25 to 37.5 cm. This is clearly indicated by the slope of the curve. The effect of length on maximum deflection is significantly influenced by the change of spacing. This is specially appearing when S_h more than 20 cm.

Combined effect of spacing and length of the strips:

Figure 9 shows the variation of maximum deflection at the vertical center line of the wall with spacing and length of the reinforcing strips.

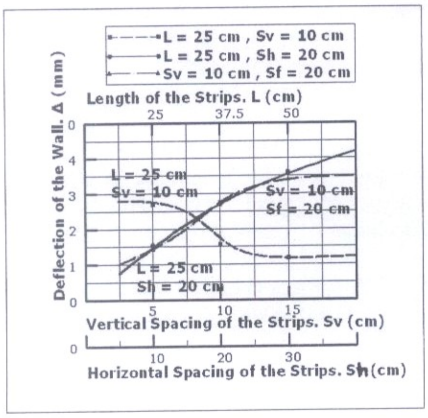


Fig. 9 Variation of Maximum Deflection with Spacing and Length of the Strips

It is found that the horizontal spacing Sh is the most affecting factor, specially when it changes between 10 and 20 cm, while the vertical spacing S_v appear to be less effective and its effect is rather uniform. The effect of strip length also shows an important effect, which is non-linear and most significant between L=25 and 37.5 cm. Figure 9 can be considered as guide chart to find the adequate spacing, if the length and permissible deflection are known and vice versa.

Conclusions

Based on the results discussed in the present research, the following conclusions have been drawn:

1. The wall deflects in a manner similar to that of a propped cantilever beam. The maximum deflection in all the cases occurred at the top of vertical center line of the wall.
2. It is found that the horizontal spacing is the most dominating factor on the deflection, and its effect is clearly pronounced in range of Sh between 10 and 20 cm.
3. Although the vertical spacing proved to have a significant effect on deflection of the wall, it's influence is rather uniform and much less than that of horizontal spacing.
4. It is concluded that the use of short strip length L=25 cm is inconvenient, as it yields into excessive deflection, even under small spacing, while the length of 37.5 cm reduce the deflection appreciably and allows the use of wider spacing in both vertical and horizontal directions.

References

1. Al-Hussaini, M. and Perry, E.B. (1978). "Field Experiment on Reinforced Earth wall". Proc. ASCE, Spring Convention and Exhibition, Pittsburgh, Pennsylvania, Preprint No. 3131.
2. Bradley, W.A. (1959). "Laterally Loaded Thin Flat Plates". Journal of the Engg. Mech. Div., Proc. ASCE, Vol. 85, No. EM4, pp. 76-107.
3. Broms,B.B. (1978). "Design of Fabric Reinforced Retaining Structures". Proc. ASCE, Spring Convention and Exhibition, Pittsburgh, Pennsylvania, Preprint No. 3128.
4. B.S.I. - 1377: (1975). "Method of Test for Soils for Civil Engineering Purposes". Inst, of Civil Engg. London.v
5. Change, J.C. and Forsyth, R.A. (1977). "Design and Field Behavior of Reinforced Earth Wall". Journal of the Geot. Engg. Div., Proc. ASCE, Vol.103, No. GT7, pp. 677-692.
6. Kolbuszewski, J.J. (1948). "An Experimental Study of Maximum and Minimum Porosities of Sands". Proc, of the 2nd Int. Conf. Soil Mech. Found. Engg. Rotterdam, Vol. l,pp. 158-165.
7. Lee, K.L., Adams, B.D. and Vagernon, J-M. J. (1973). "Reinforced Earth Retaining Walls". Journal of soil Mech. Found. Div., Proc. ASCE, Vol. 9, No. SM10, pp. 745-763.
8. Richardson, G.N. and Lee, K.L. (1975). "Seismic Design of Reinforced Earth Walls". Journal of the Geot. Engg. Div., Proc. ASCE, Vol. 103, No. GT1, pp. 1-17.
9. Richardson, G.N., Ferger, D., Fong, A. and Lee, K.L. (1977). "Seismic Testing of Reinforced Earth Walls". Journal of Geot. Engg. Div., Proc. ASCE, Vol. 103, No. GTl.pp. 1-17.
10. Smith, A.K.C. and Bransby, P.L. (1976). "The Failure of Reinforced Earth Walls by Overturning". Journal of the Geot. London, Vol. 26, pp. 376-381.

الخلاصة:

يتضمن هذا البحث تاثير كل من المباعدة العمودية والافقية، بالاضافة الى طول شرائط التسليح ، على السلوك الانشائي لنموذج جدار ساند لتربة مسلحة.

انجزت التجارب على نموذج مختبري صغير استخدم فيه رمل منتظم التدرج كمادة املائية . وضع الرمل في حالة كثافة عالية باستخدام طريقة تمطير الرمل . سلح الرمل بشرائط من الالمنيوم الرقيق ، اختيرت ابعادها المقطعية بحيث يكفي لمنع الفشل بالقطع . مثل الجدار الساند بلوحة شفافة من البلاستيك.

اظهرت النتائج بان مباعدة الافقية اكثر تاثيرا على انحناء الجدار الساند مقارنة بالمباعدة العمودية لشرائط التسليح . وجد بموجب هذا البحث بان القيم الحرجة للمباعدة الافقية والعمودية لشرائط التسليح هي ٢٠ و١٠ سم على التوالي وهذا يبين بان الطول القصير لشرائط التسليح يؤدي الى انحناء متزايد حتى في حالة استخدام مباعدة افقية وعمودية قليلة لشرائط التسليح.