CENTRIFUGE MODEL TESTING OF A REINFORCED SOIL WALL

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ABSTRACT

This paper reports the research conducted on the centrifuge modeling of a certain type of reinforced soil wall in the National University of Singapore, Singapore. Some of the previous works on centrifuge model tests on reinforced soil structures are reviewed. Series of centrifuge model testings on walls of heights 4.5m, 10.5m and 15.0m were carried out. The models were spun to as high as 170 g in certain cases in order to bring about failure to the model walls. The observed failure patterns of the walls are discussed. Based on the results of these tests, it was concluded that the present method of design of the wall is adequate albeit conservative. In addition, the failure patterns are consistent with established Rankine theory and other relevant previous research.

Keywords: Centrifuge modeling; Reinforced soil

1. INTRODUCTION

A new and innovative type of reinforced soil wall system was developed in Malaysia in 1993. Since then, many such walls have been successfully constructed in Malaysia, Singapore and India. The system is designed with the similar concept as the conventional reinforced soil wall using geosynthetics or metallic strip reinforcements, except that an additional anchorage element at the end of the reinforcement bar is added. The field performances for these walls have been satisfactory. However, there is a need to verify the assumed failure mechanism. Instead of loading an actual full-scale size wall to failure, the failure mechanism can be modelled using the centrifuge method. The advantages of centrifuge modelling are that it is more cost effective, reliable and repeatable. Some of the previous works on centrifuge model tests of reinforced soil structures are reviewed. A series of centrifuge model testing on the Reinforced Soil (RS) walls were carried out at National University of Singapore to model the failure mechanism.

2. REVIEW OF PREVIOUS STUDIES

Bolton (1984) was one of the earliest researchers to carry out centrifuge testing to study the behavior of reinforced soil walls. In 1984, Bolton reported the results of the model study on the anchored earth wall developed by Transport Road Research Laboratory, UK. The reinforcements consist of round bars bent into Z-shaped at the free ends to form the anchors. The study was carried out on the Cambridge University geotechnical centrifuge. The model wall collapsed at 22g. On examination of the model, the conditions sketched in *Figure 1* were revealed. There was evidence of an active zone of triangular wedge of collapse behind the facing.

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Mitchell et. al. (1988) conducted 38 number of centrifuge tests on model walls of various different reinforcements, facing and backfill material.

The objective of the study is to establish the failure modes of these various reinforced soil systems.

The tests were conducted with 150mm high model walls using the Schaevitz centrifuge at the University of California at Davis.

Regardless of the type of reinforcement, all walls exhibited an initial failure plane inclined at 21° to 25° to the vertical.

However, it is observed that for stiffer reinforcements, the failure is more sudden than those with more ductile reinforcements.

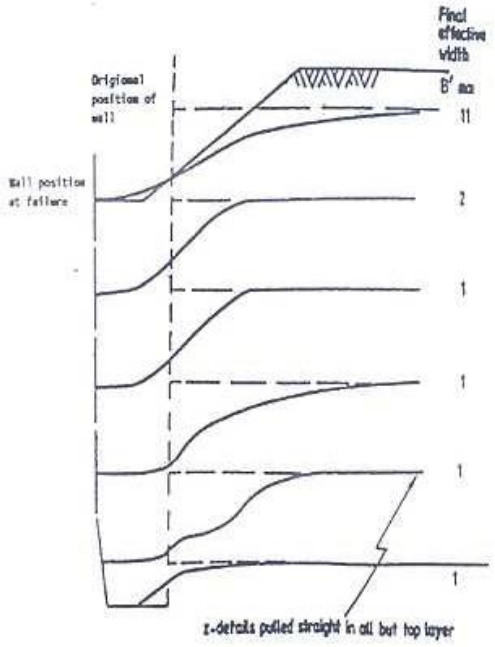

Figure 1: Disposition After Test (after Bolton, 1984).

It is seen from the above review that the previous studies are conducted on either frictional reinforced soil type of wall or anchored earth type with Z-shape anchors. No previous studies have been conducted on the reinforced soil type of wall where the anchors consists of concrete blocks acting like deadmen. As a result, National University of Singapore (NUS) was commissioned to carry out the centrifuge testing of the reinforced soil wall to examine and evaluate the failure mechanism.

3. TEST SET UP

The geotechnical centrifuge *Figure 2* in NUS was used to carry out the tests. The model set up placed on the centrifuge swinging platform is shown in *Figure 3*. The size of the model container is 210mm wide by 750mm long by 500mm high. The centrifuge model was designed based on the dimensions of the Reinforced Soil (RS) wall using a scaling factor, N.

The model wall was made of 3mm thick aluminium, the model anchors were made of 3mm thick aluminium strips and the reinforcing tendons were modelled by 0.5mm diameter steel wire. The sand used was a uniform angular fine silica sand with a mean grain diameter of 0.2mm, a uniformity coefficient of 2.4 and a specific gravity of 2.64. In order to observe the failure pattern clearly, thin uniform layer of blue coloured dyed sand (each of 5mm thick) were placed at every 25mm vertical interval in the sand mass. Greased polythene sheets were placed between the side of the container and the model to reduce side wall friction.

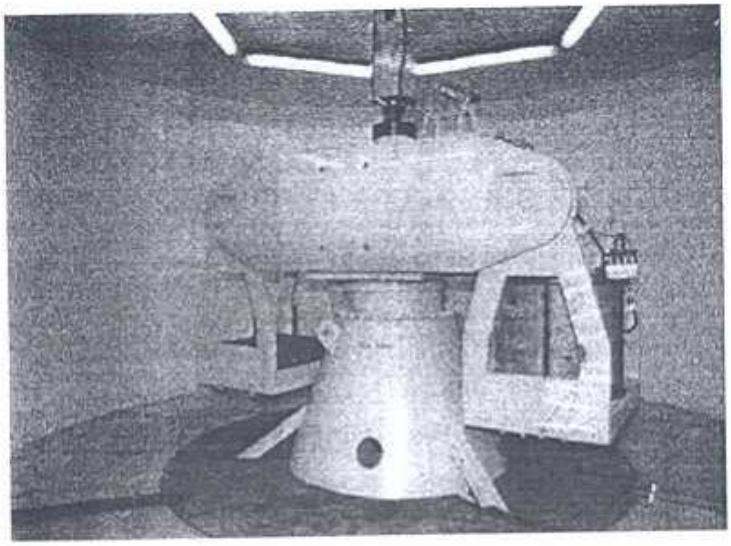

Figure 2: NUS Geotechnical Centrifuge

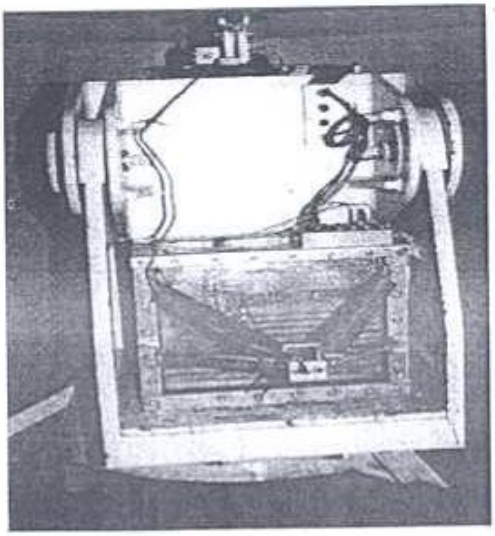

Figure 3: Experimental Setup

4. TEST PROGRAMME

Five test series were conducted to simulate the reinforced soil wall with heights ranging from 4.5m to 15m with a width height ratio of between 0.72 and 0.79. A summary of the test programme is shown in *Table 1*. The tests were conducted by accelerating the centrifuge from at rest position to the maximum g level permissible for the given model weight.

If no failure was observed at the maximum g level, the test would be repeated either; (a) by placing surcharge on the backfill, or (b) by debonding a selected number of anchors by removing the nuts of the corresponding reinforcing tendon at the model wall panel. During the test, the revolving speed of the centrifuge, ω was recorded by a speedometer and the centrifuge acceleration field Ng (g level) with reference to the lower third height of the model wall can be determined as:

$$Ng = \omega^2 r/9.81$$

Where r is the radius of the centrifuge to the lower third height of the wall.

Table 1: Summary of test details

Test series	Test Number	Sand	Model Dimension					Max. g-level	Results
			Wall ht. (mm)	Length of tendon (mm)	Anchor width & ht. (mm)	Vertical spacing of anchors (mm)	Remarks		
Test 1 Low Wall	Test 1A	Very loose RD~30%	240	190	200 x 12.7	47.7 (5 rows of continuous anchors)	No surcharge	110g	No failure
	Test 1B							160g	
	Test 1C						q = 4.09 kPa	160g	
	Test 1D						q = 7.45 kPa	130g	
Test 2 Low Wall	Test 2A	Very loose RD~30%	240	190	12.7 x 12.7	95.4 (2 rows of 3 anchors)	No surcharge	22g	No failure
	Test 2B							67g	
	Test 2C						2 anchors debonded	130g	Failure at 110g
Test 3 Low Wall	Test 3A	Very dense RD~87%	240	190	12.7 x 12.7	95.4 (2 rows of 3 anchors)	No surcharge	165g	No failure
	Test 3B						q = 7.2 kPa	155g	
	Test 3C						2 anchors debonded	170g	
	Test 3D						4 anchors debonded	63g	Failure at 63g
Test 4 Medium Wall	Test 4A	Dense RD~70%	265	190	5 x 5	37.5 (6 rows of 3 anchors)	No surcharge	170g	No failure
	Test 4B						4 anchors debonded	170g	Failure at 130g
Test 5 High Wall	Test 5A	Dense RD~70%	430	315	8 x 8	60 mm (2 rows of 3 anchors)	No surcharge	120g	No failure
	Test 5B						4 anchors debonded	95g	Failure at 90g

5. RESULTS

The summary of test results is shown in *Table 2*. From the summary, it is seen that there is no sign of distress at the intended g level which would simulate the prototype wall height. Failure is achieved at much higher g level and only after debonding some anchors.

Due to lack of space, only the test results of test series 4B are shown in detail. Test series 4B is for medium height of wall at 10.5m.

The intended g level was 40g. However, in order to induce failure, four anchors were debonded and the centrifuge was accelerated to 130g.

Figure 4 shows the displacement and tilt angle of the wall at various g levels. *Figure 5* and *Figure 6* show the model wall before and after the test to failure.

After the test, epoxy was carefully poured over the sand to preserve the failure planes and zones.

A photograph of the epoxy preserved failure patterns is shown in *Figure 7*.

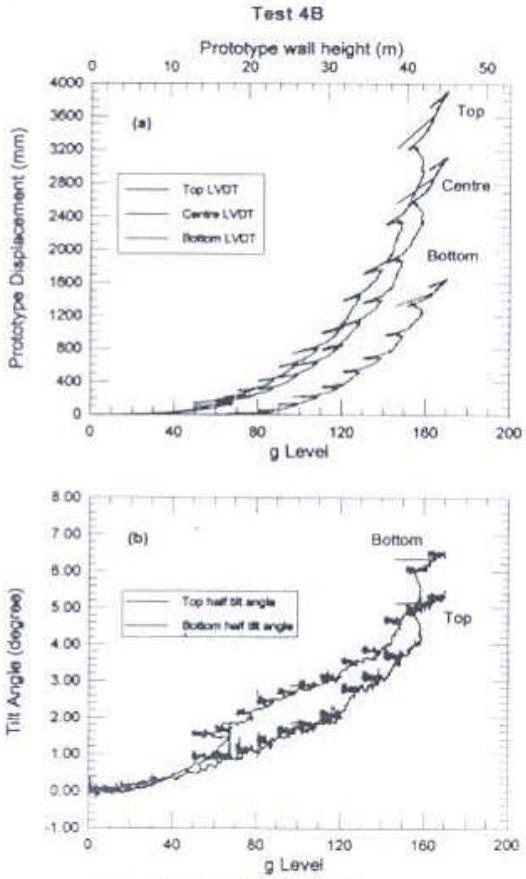

Figure 4: Results of Test 4B

Table 2: Summary of the test results

Test Series	Wall ht. and sandfill density	Model dimension		Intended g-level	Prototype at intended g-level			Failure g-level	Wall g / Intended g	Wall top deflection /ht.	Wall tilt angle
		Wall ht. (mm)	Anchor size (mm x mm)		Wall ht. (m)	Anchor size (mm x mm)	Estimated wall top deflection (mm)				
Test 2	Low Wall, Loose, RD=30%	240	12.7 x 12.7	19g	4.5	240 x 240	~105mm	110g (after debonding 2 anchors)	5.8	2.3%	0.92°
Test 3	Low Wall, RD=87%	240	12.7 x 12.7	19g	4.5	240 x 240	~35mm	63g (after debonding 4 anchors)	3.3	0.8%	0.23°
Test 4	Medium Wall, RD=70%	265	5 x 5	40g	10.6	200 x 200	~150mm	130g (after debonding 4 anchors)	3.2	1.4%	0.57°
Test 5	High Wall, RD=72%	430	8 x 8	35g	15.1	280 x 280	~150mm	90g (after debonding 4 anchors)	2.6	1.0%	0.92°

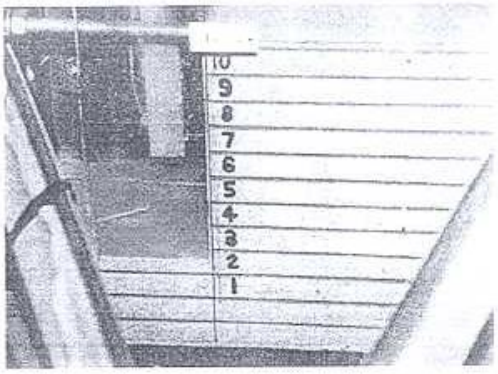

Figure 5: Side Elevation Before Test

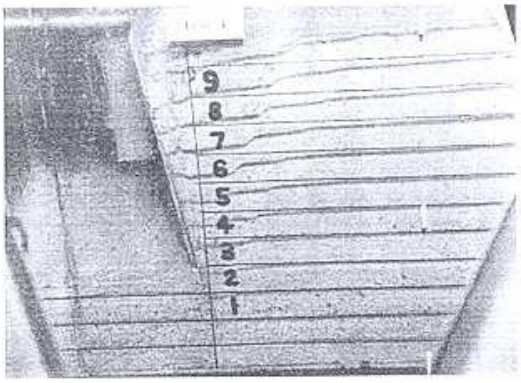

Figure 6: After Test

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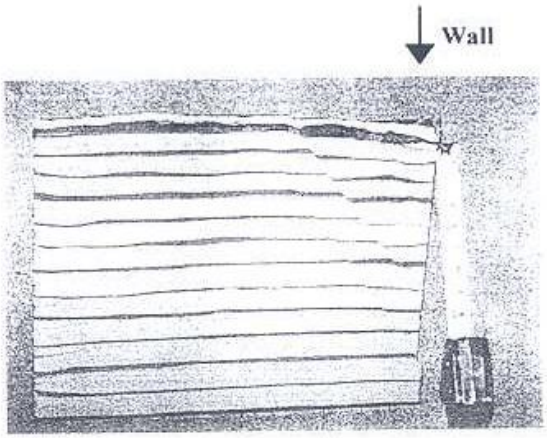

Figure 7: Failure Pattern of Test 4B

6. DISCUSSION

The failure pattern behind the wall, which consists of a series of parallel straight lines, is observed to make an angle of about 29°, which is fairly close to the Rankine failure plane. The measured failure angle is also consistent with those observed by Mitchell et. al. (1988). On the other hand, the failure pattern in front of the anchor is roughly a spherical bulb of size between 1.75 to two times the anchor height. This is consistent to those observed by Dickin and Leung (1985).

The wall displacement and tilt angle recorded for the simulated prototype wall heights at the intended g level were relatively small i.e. in the order of 0.8% to 2.3%.

7. CONCLUSION

Based on the centrifuge study carried out on the reinforced soil walls of heights 4.5m, 10.5m and 15m, the following conclusion can be derived:

7.1 The present method of design for the reinforced soil wall appears to be adequate as the model wall could only be failed at much higher g than intended and only after some anchors were debonded.

7.2 The failure patterns are consistent with established Rankine theory and previous research.

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