Behavior of cellular reinforced soil wall under uniformly distributed load

Khedkar, M.S.
Research Scholar, Department of Civil Engineering, Indian Institute of Technology Bombay, Powai, Mumbai - 400076, INDIA.

Mandal, J.N.
Professor, Department of Civil Engineering, Indian Institute of Technology Bombay, Powai, Mumbai – 400076, INDIA.

Keywords: cellular reinforcement, reinforced soil wall, geogrid, finite element model

ABSTRACT: At present, reinforced soil wall with various planar reinforcing elements like strips, textiles and grids are more common for carrying uniformly distributed surcharge loads. Cellular reinforcement is a three dimensional reinforcement for soil applications. In the present paper, the concept of cellular reinforced soil wall is presented. The behaviour of cellular reinforced soil wall is studied under the uniformly distributed surcharge load and compared with the conventional grid reinforced soil wall. Reduced scale laboratory experiments are carried out on cellular reinforced soil wall as well as on grid reinforced soil wall with various intensities of uniformly distributed load. Four different heights of cellular reinforcement are considered in the experimental program. The deformation behaviour is studied by measuring panel displacement of wall at various incremental surcharge loads till failure of wall. It is observed that, under the same intensity of uniformly distributed surcharge load, cellular reinforced soil wall perform better than grid reinforced soil wall. Increase in height of cellular reinforcement demonstrated greater uniformly distributed surcharge loads at failure. Also, for a particular intensity of uniformly distributed surcharge load, increase in height of cellular reinforcement illustrated lesser panel displacement. Finite element method is used to compare the experimental results. A computer code Plaxis V8 is used to simulate the grid and cellular reinforced soil wall and the deformations were observed.

1 INTRODUCTION

In recent past, extensive use of reinforced soil retaining wall systems have been seen for carrying surcharge loads, along with the self weight of the backfill soil. Several researchers have studied the planar reinforced soil wall, e.g. Hatami et al. (2001), Shinde & Mandal (2007), Ma & Wu (2004) and Hatami & Bathurst (2006). Soil reinforcement using of cellular reinforcement (geocell) has been utilized successfully in many areas of geotechnical engineering such as bearing capacity improvement under footing, road and embankments; however, there is still need to study the probable use of cellular reinforcement in reinforced soil retaining wall. Zhang et al. (2006), Khedkar & Mandal (2007), Khedkar & Mandal (2007), Khedkar et al. (2008), and Khedkar & Mandal (2009b) have proposed three dimensional cellular reinforcement for reinforced soil applications with the help of triaxial or pullout tests. However, plane strain model behaviour is more practical to understand the performance of cellular reinforced soil retaining wall. Present paper focuses the behaviour of cellular reinforced soil wall.

2 EXPERIMENTAL INVESTIGATIONS

Experimental investigations are planed with reduced scale laboratory model of cellular reinforced soil wall to study mainly the deformation behaviour of cellular reinforced wall under strip loads. The deformation behaviour of the cellular reinforced soil wall was also planed to compare with the geogrid reinforced soil wall. Table 1 demonstrates the details of experimental test program.

Table 1. Details of experimental program

Model	Reinforcement		
	Type	Length	Spacing
Model-A	Unreinforced	0	0
Model-B	Geogrid (GG)	0.7 H	0.22 H
	CR10	0.7 H	0.22 H
Model-C	CR3	0.7 H	0.22H
	CR20	0.7 H	0.22 H
	CR30	0.7 H	0.22 H

Where, H = height of wall, CR3, CR10, CR20 and CR30 = 3 mm, 10 mm, 20 mm and 30 mm high cellular reinforcements, respectively.

Test program was divided into different groups according to the study objective. Model-A was included to check the response of unreinforced soil retaining wall. Model-B was to study the deformation behavior of cellular reinforced wall under uniformly distributed load and compare it with the planar grid reinforced soil wall. Finally, Model-C was included to study the deformation behavior of cellular reinforced wall under uniformly distributed load with different height of reinforcements (i.e., with different stiffness).

2.1 *Experimental Test Setup*

A laboratory test set up was developed to perform the entire experimentation as per the experimental plan. Considering the modelling laws and laboratory model limitations, the test layout of reinforced soil wall was designed to simulate 2.1 m high wall with a scale factor of 1 (Model): 4 (Prototype). Fig. 1 illustrates the laboratory test layout of reinforced soil wall.

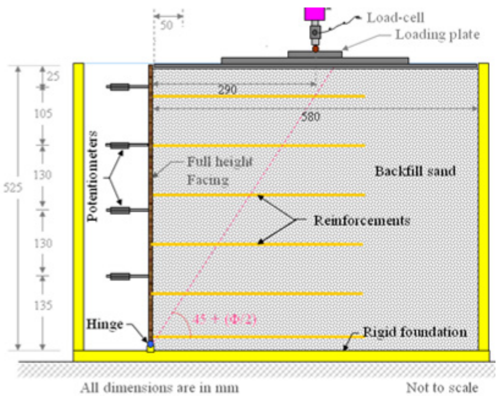


Figure 1. Test layout of reinforced soil wall

In order to perform the tests, a custom designed experimental test set up was fabricated. The internal dimensions of test tank were measured as 400 mm wide x 550 mm high x 700 mm long. The test tank was facilitated to accommodate the reinforced wall model of size 580 mm (length of wall) by 525 mm (height of wall). The model test wall was positioned at 120 mm from the front face of the tank in order to accommodate the wall deformations, including the failure deformations during the collapse stage.

The scope of testing program includes study of cellular reinforced soil retaining wall with full height facing. Therefore, stiff plywood of 7 mm thickness, with 525 mm height and 400 mm in width was used for all the laboratory experiments, to simulate the independent full height facing. All the potentiometers along with the load cell were connected to data logging system. All the instrumentation was calibrated before use.

2.2 *Evaluation of Material Properties*

White colored quartz sand with mean particle size of 0.85 mm was used for experimental study. Physical properties of sand includes uniformity coefficient = 1.38; coefficient of curvature = 0.96; minimum dry unit weight = 16 kN/m^3; specific gravity = 2.5; maximum dry unit weight = 18 kN/m^3 and peak friction angle of sand at 47.9 % relative density (from direct shear test) = 34º. The sand can be classified as poorly graded sand, 'SP' according to Indian Standard classification (IS 1498 – 1970). Two types of reinforcement are used in the present study; i.e., the cellular reinforcements and planar grid reinforcement. Model cellular reinforcements have been designed by considering the modeling laws. They were manufactured manually from high density polyethylene material available locally. The material was cut in to longitudinal and transverse members of required height to ultimately suture them with the help of cotton thread. Fig. 2 illustrates the manually manufactured 10 mm high cellular reinforcement. The width of cellular reinforcement was 390 mm and the length was 0.7 H. The longitudinal and transverse cell dimensions of all the reinforcements were kept constant i.e., 30 mm x 30 mm

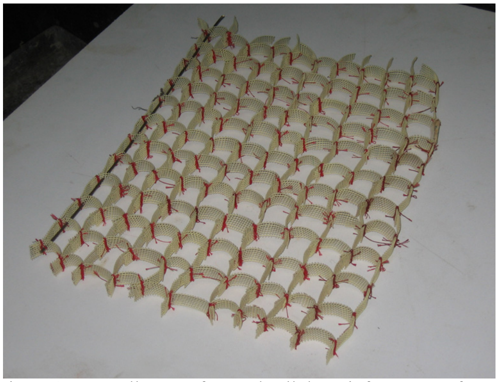


Figure 2. Manually manufactured cellular reinforcements for experimental investigations

Aim of the present study includes comparison of behaviour between cellular reinforcements and planer grid reinforcement. In this regard, it was important to select the two reinforcement; ideally, having similar tensile and interface properties. For this purpose extensive material survey was carried out for the tensile strength and interface properties of grid reinforcements; however, the aperture size of geogrid was selected same as that of cellular reinforcements. In order to determine the tensile strength of all the specimens, including 10 mm high cellular reinforcement, the samples were prepared according to ASTM D 6637 (Method B). From the test results, it is observed that geogrid failed at 0.91 kN/m strength for a corresponding strain of 4.96%; which is nearly closer to the tensile strength and the corresponding strain of 10 mm high cellular reinforcement (CR10). The numerical values of test results are mentioned in Table 2. Soil - reinforcement interface were determined from modified direct shear test, which is observed as 31° for geogrid as well as for cellular reinforcements.

Table 2. Properties of reinforcements

Reinforcement properties	Aspect ratio (S/h) (Dimensionless)	Tensile strength (kN/m)	Elongation at maximum strength (%))
GG	(30/3.5) = 8.6	0.91	4.96
CR3	10	0.34	4.81
CR10	3	0.89	4.78
CR20	1.5	1.33	4.7
CR30	1	1.9	4.52

Where, ‘S’ is the spacing between the transverse members of cellular reinforcement and ‘h’ is the height of cellular reinforcement

2.3 *Sample Preparation and Test Procedure*

In order to replicate the samples through - out the testing program, the following step by step procedure was adopted to prepare the sample. A 25 mm layer of sand is placed on the bottom of tank to act as a foundation layer. Full height facing panel is then placed, allowing the rotation of panel on loading. The reinforcement thus instrumented was then placed directly on the foundation layer and connected to the full height facing panel. A very thin layer of coloured sand was placed on the reinforcement to represent reinforcement for deformation analysis. Backfill sand was placed in 25 mm layers by pluvial method on the reinforcement. Also, an electrically operated handy vibrator was used to compact the sand layers to the required relative density of 47.9%. Potentiometers were installed on the facing panel to measure the horizontal displacement of panel also load cell was connected to the loading system to record the surcharge load.

After completion of sample preparation the surcharge pressure was applied by using the hydraulic jack, through the loading plate.

3 EXPERIMENTAL RESULTS AND DISCUSSIONS

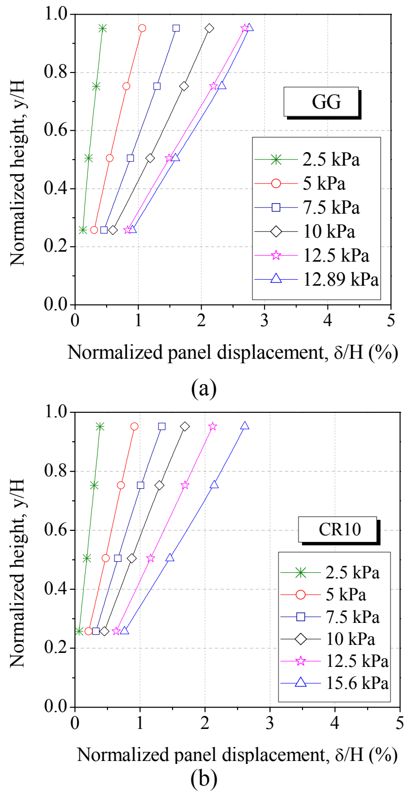
Total 12 numbers of tests were conducted in the laboratory, out of which 3 number of test were pilot tests and 3 numbers of tests were conducted to check the repeatability of results. Thus, total 6 numbers of tests are reported in the present paper. The load was applied in increments to measure the horizontal displacement of panel with the help of potentiometers. The failure is defined as the condition when the measured load can be seen decreasing with increase in horizontal displacement at the potentiometers.

3.1 *Model A*

Model A was with unreinforced sand. A complete collapse failure was seen as soon as the supports were removed.

3.2 *Model B*

Model B was tested for the uniformly distributed surcharge load with the reinforcement length of 0.7 H and the spacing of 0.22 H in between them. Fig. 3 illustrates the panel displacement against wall height for the case of geogrid and 10 mm high cellular reinforcement. Height of wall is normalized with the vertical distance from base of wall and the panel displacement is normalized by dividing with the height of wall. From Fig. 3 (a) and (b) for a particular surcharge load; it can be observed that, the normalized panel displacement increase with increase in height of wall indicating the maximum panel displacement at top heights of wall. Also, the displacement increases with increase in surcharge pressures.



(Where, H = height of wall, y = height at particular level measured from the bottom of wall, δ = panel displacement)

Figure 3. Relationship between normalized height and normalized panel displacement at various surcharge pressures for Model B: (a) Geogrid (GG); and (b) 10 mm high cellular reinforcement (CR10)

Fig. 4 shows the comparison of panel displacement for geogrid case and 10 mm high cellular reinforcement case for the length of 0.7 times the height (0.7 H) and the spacing of 0.22 H. Under the uniformly distributed pressure of 5 kPa, normalized panel displacement for cellular reinforced wall is lesser than that of the geogrid reinforced case. Similarly, for 12.5 kPa of surcharge pressure cellular reinforcement shows lesser panel displacement indicating the better performance over the geogrid reinforcement. Also, for 12.5 kPa surcharge pressure, it is observed that, the relative displacement between geogrid and cellular reinforcement is comparatively smaller in the top heights, than that of the bottom portion of wall.

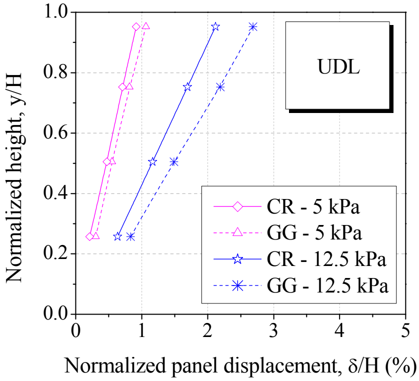


Figure 4. Comparison of normalized height versus normalized panel displacement for geogrid (GG) and cellular reinforcement (CR) at various surcharge pressures

3.3 *Model C*

In order to study the effect of variation of height of cellular reinforcement on behaviour of wall, Model C was tested with different heights of cellular reinforcements; i.e., 3 mm, 20 mm, and 30 mm; for the reinforcement length of 0.7 H and the spacing of 0.22 H. Fig. 5 and Table 3 illustrates the maximum panel displacements and the corresponding surcharge pressures for Model B and Model C walls, reinforced with various reinforcements.

The surcharge pressure is normalized with the equivalent height of backfill and maximum panel displacement is normalized with the height of wall, expressed in percentage. It can be seen that the 30 mm high cellular reinforcement shows increased failure pressure compared to other cellular reinforcements i.e., 3 mm to 20 mm high cellular reinforcements. The cause attributed to this may due to the stiffer reinforcement material due to increased height of reinforcement. Thus increase in height of cellular reinforcement demonstrated greater uniformly distributed surcharge loads at failure. It is also observed that 10 mm high cellular reinforcement carries greater surcharge pressure at failure than that of the geogrid reinforced wall.

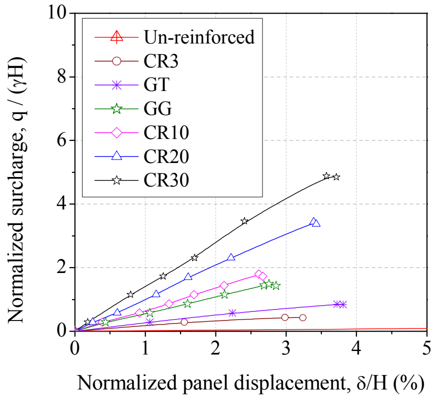


Figure 5. Relationship between normalized maximum surcharge pressures and normalized panel displacement for wall with various reinforcements

Table 3. Maximum normalized surcharge pressures and corresponding normalized panel displacement for wall with various reinforcements

Reinforcements	Normalized surcharge (q/γH) (dimensionless)	Normalized panel displacement (δ/H) (%)
Geotextile GT)	0.84	3.80
Geogrid (GG)	1.4	2.85
CR3	0.42	3.23
CR10	1.73	2.66
CR20	3.37	3.42
CR30	4.84	3.71

Where, δ = panel displacement, H = total height of wall and q = applied surcharge pressure

4 FINITE ELEMENT SIMULATION

In the present study, the laboratory experimentation was scoped up to the deformations study of cellular reinforced wall. However, the probable generation of stresses in the wall along with the probable deformations is studied with the help of finite element method. Input program of Plaxis V8 was used for this purpose. In the geometrical modelling of geogrid and cellular reinforced wall, the vertical boundary is fixed horizontally, so that the sand cannot move horizontally beyond the boundary however, the vertical settlement of sand is permitted. Bottom boundary is modeled by total fixity. Facing panel is modeled by plate element. The panel is hinged at the bottom of wall, allowing its rotational movements.

The uniformly distributed surcharge pressure was modelled by uniformly distributed load per meter, on top surface of sand cluster. For simulation purpose, the cellular reinforcement is divided in to two parts, i.e., longitudinal members and transverse members. Longitudinal members are modeled by geogrid elements and transverse members are modeled by plate elements, as stiffness is the important parameter for transverse member. Sand was modeled using Mohr-Coulomb model with 15-noded triangular elements. Longitudinal members are modeled by geogrid elements and transverse members are modeled by plate elements.

The geogrid elements were represented with their axial stiffness, EA. While, the plate elements were modeled with flexural rigidity (EI), in addition to the axial stiffness of the reinforcement. The axial stiffness, EA, can be determined from stress strain properties of reinforcement. Axial stiffness of geogrid and 10 mm cellular reinforcement is taken as 18.3 and 18.6 kN/m width of wall. Thus to simulate the stiffness of the transverse member, an equivalent depth (d_{eq}) of 2 mm was specified to the transverse members. The plate element of facing panel was modeled with the flexural rigidity of 325 kN-mm^2/mm and the axial stiffness of plywood was calculated by considering the equivalent depth as 7.5 mm. The interface is modeled by virtual thickness interface element which is calculated as the Virtual thickness factor times the average element size. According to Vermeer & Brinkgreve (1995), for Plaxis program, the interaction coefficient, R, (R_{inter}, in case of Plaxis V8) is defined as the ratio of the shear strength of soil-structure interface to the corresponding shear strength of the soil. To simulate the soil structure interaction (R_{inter}) for planar as well as cellular reinforcements, the test results from modified direct shear tests are used.

4.1 *Finite Element Analysis Results and Discussions*

The finite element program for geogrid and 10 mm high cellular reinforced soil wall was developed for different uniformly distributed surcharge pressures. To compare the behaviour of both the cases; here, the results are presented for a particular surcharge value of 12.5 kPa. It is visualized from Fig. 6 (a and b) that the extreme total displacement is at the top layers in the both the cases. Also, extreme total displacement for geogrid case is greater than that of the cellular reinforced case.

Fig. 7 shows the axial forces in the reinforcement layers for the geogrid and 10 mm high cellular reinforcement at 12.5 kPa of uniformly distributed surcharge pressure. The maximum axial force is observed near the facing of wall. The forces in the cellular reinforcement Fig. 7 (b) are seen more uniformly distributed than the geogrid case Fig. 7 (a), especially in Layer 3. Consequently, less amount of maximum axial forces are seen to resist the applied surcharge pressure of 12.5 kPa. Residual forces are seen in case of geogrids but cellular reinforcements show nearly zero residual forces at the backfill end of reinforcements, which demonstrates the better interaction in between soil and cellular reinforcement as compared to that of geogrid case.

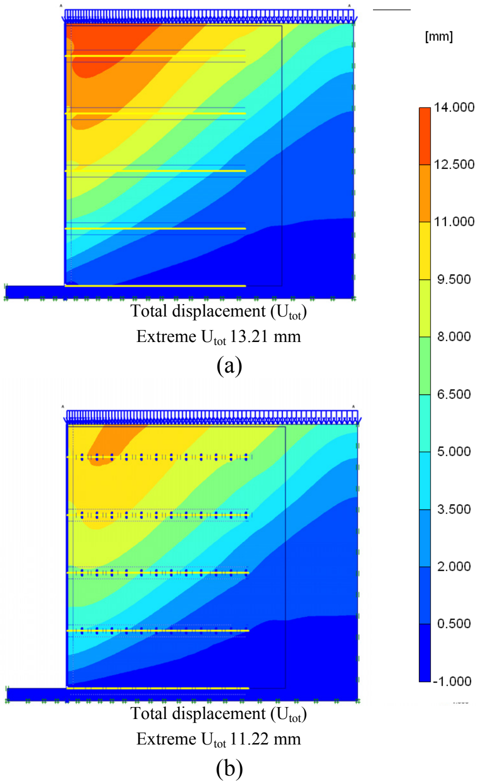
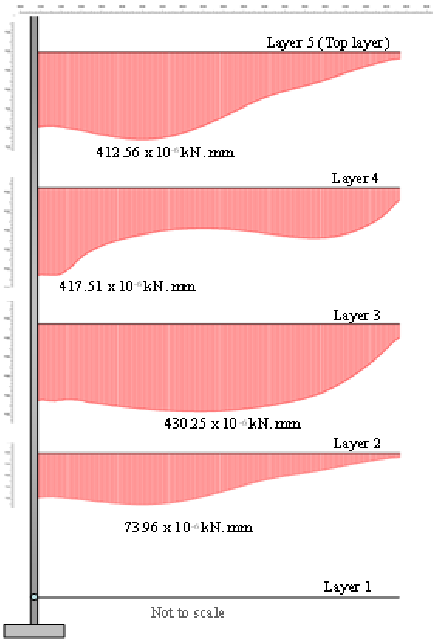


Figure 6. Extreme total displacement shedding plot: (a) Geogrid reinforced wall; (b) Cellular reinforced wall

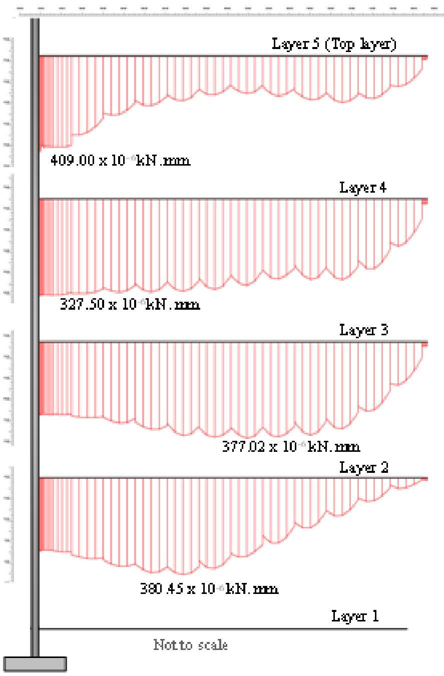
5 CONCLUSIONS

Following major conclusions can be seen from present study:

1. Increase in height of cellular reinforcement demonstrated greater uniformly distributed surcharge loads at failure.
2. For a particular surcharge value, cellular reinforced wall shows reduced normalized panel displacement as compare to geogrid reinforced wall indicating better performance of cellular reinforced wall over the grid reinforced wall.
3. It can be seen that the 30 mm high cellular reinforcement shows increased failure pressure as compared to 3 mm, 10 mm and 20 mm high cellular reinforcements cellular reinforcements.
4. Residual axial forces are seen in case of geogrids however cellular reinforcements shows nearly zero residual forces at the backfill end of reinforcements, which demonstrates the better interaction in between soil and cellular reinforcement as compared to that of geogrid case.



(a)



(b)

Figure 7. Axial forces in various reinforcement layers: (a) geogrid case; and (b) cellular reinforcement case

REFERENCES

ASTM D 6637. 2001. Determining tensile properties of geogrids by the single or multi-rib tensile method, *ASTM, Philadelphia*, PA, USA.

Hatami, K. & Bathurst, R.J. 2006. Numerical model for reinforced soil segmental walls under surcharge loading, *Journal of Geotechnical and Geoenvironmental Engineering,* Vol. 132 (6), pp. 673-684.

Hatami, K., Bathurst, R.J., & Pietro, P., 2001. Static response of reinforced soil retaining walls with nonuniform reinforcement, *International Journal of Geomechanics* Vol. 1 (4), pp. 477–506.

IS 1498: 1970. (Reaffirmed 2002) Classification and identification of soils for general engineering purposes, *Indian Standards,* New Delhi, India, pp. 1-26.

Khedkar, M.S. & Mandal, J.N. 2007. Pullout response study for cellular reinforcement. *In: pro. of 5th Int. Symp. on Earth Reinforcement, IS Kyushu '07,* November 14-16, 2007, Japan, pp. 293-298.

Khedkar, M.S., Mandal, J.N., & Shinde, A.L., 2008. Reinforced wall with restricted backfill zone in urban areas, *In: pro. of Int. Geotechnical Conference on 'Development of urban areas and geotechnical engineering,* June 16–19, 2008, Russia. Vol. 1, pp. 239 – 244.

Khedkar, M.S. & Mandal, J.N., 2009a. Pullout response of cellular reinforcement under low normal pressures. *International Journal of Geotechnical Engineering,* Vol. 3 (1), pp. 75-87.

Khedkar, M.S. & Mandal, J.N., 2009b. Pullout behaviour of cellular reinforcements, *Geotextiles and Geomembranes*, Vol. 27 (4), pp. 262-271.

Ma, C.C. & Wu, J.T.H. 2004. Field performance of an independent full-height facing reinforced soil wall, *Journal of performance of constructed facilities, ASCE*, Vol. 18 (3), pp. 165- 172.

Shinde, A. & Mandal, J.N. 2007. Behavior of reinforced soil retaining wall with limited fill zone, *Int. Jl. of Geological and Geotechnical Engineering*, Vol. 25 (6), pp. 657-672

Vermeer P.A & Brinkgreve R.B.J. 1995. Finite element code for soil and rock analysis, *A.A. Balkema*, Rotterdam (Netherlands)

Zhang, M.X., Javad, A.A. & Min, X. 2006. Triaxial tests of sand reinforced with 3D inclusions, *Geotextiles and Geomembranes*., Vol. 24 pp. 201-209.