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Pullout response study for cellular reinforcement

M.S. Khedkar & J.N. Mandal
Department of Civil Engineering, Indian Institute of Technology Bombay, Powai, Mumbai, India.

ABSTRACT: Various forms of reinforcing elements have been used for construction of reinforced soil retaining wall i.e., sheets, grids, meshes, strips, bars, rods etc. In ultimate limit state design, considering the internal stability analysis, the reinforced soil wall may fail in tension/rupture or pullout type of failure. Pullout tests results are commonly used to predict actual field pullout performance of reinforcements. Various authors have studied different kinds of shapes and sizes of reinforcements for pullout test, but much attention has not been given to conduct pullout test with cellular reinforcement like geocell. Though Soil reinforcement using of cellular reinforcement (geocell) has been utilized successfully in many other areas of geotechnical engineering, there is still need to study the probable use of cellular reinforcement in reinforced soil retaining wall. In the present paper, cellular type geometry of reinforcement is proposed for reinforced soil applications. Pullout analysis of such reinforcement is performed. Also, the pullout test conditions are simulated in finite element method, with the help of readymade software, Plaxis-V8 and the outputs are visualized. The results are found supportive to the assumptions made in the analysis.

1 INTRODUCTION

In conventional reinforcement soil structures two dimensional reinforcing elements are seen till date. In this paper, concept of cellular type geometry of reinforcement is introduced.

1.1 *Reinforcement geometry*

Internal stability of reinforced soil structures rely very much upon reinforcing elements. Three types of reinforcement geometry can be considered according to FHWA (2001), i.e., (1) linear unidirectional, (2) composite unidirectional and (3) planar bidirectional. Yang and Wang (1999) proposed a new reinforced soil structure composed of horizontal reinforced concrete grids. Xie (2003) presented a new type of reinforcement, reinforcing ring, whose mechanical function is to turn lateral earth pressure to stress within the reinforcing ring. Zhang et al. (2006) have conducted several triaxial tests on sand reinforced with a single layer of three dimensional (3D) reinforcing elements, and demonstrated the acceptability and better performance of 3D reinforcement over horizontal two dimensional (2D) reinforcement.

1.2 *Pullout resistance of reinforcement*

Jewell et al. (1985) and Palmeira & Milligan (1989) have demonstrated that, in case of grid reinforcement bearing mechanism governs, which changes to more frictional in nature as the spacing between bearing members is reduced.

Pullout test analysis of grid reinforcement has been conducted by several researchers in literature (Sobhi and Wu, 1996; Bakeer et al., 1998; Gurung and Iwao, 1999; Perkins and Cuelho, 1999; Gurung, 2000; Sugimoto et al., 2001 and Palmeira 2004). In particular, Jewell et al. (1985) have given the range to calculate the bearing stress ratio (σ'_b/σ'_n) depending upon the angle of friction of soil and has set upper and lower limit as general shear and punching shear failure; where, σ'_b = bearing stress and σ'_n = normal stress. Matsui et al. (1996) proposed an equation to calculate (σ'_b/σ'_n) which lies between the general shear and punching shear limits given by Jewell et al. (1985).

Bergado (1987) found that bamboo grids have a higher pullout resistance than Tensar SS2 geogrids provided that each has the same plan area. The reason may be attributed to the thicker transverse member for the bamboo than the Tensar geogrid. Various researchers like, Palmeira and Milligan (1989); and Ghionna et al. (2001) have shown that values of pullout bearing resistance are largely influenced by the reinforcement geometry, extensibility and soil dilatancy.

From literature (e.g., Madhav et al., 1998 and Moraci & Gioffre, 2006) it is very clear that, pullout study is essential and has direct implications on design of reinforced soil structures. However, no work

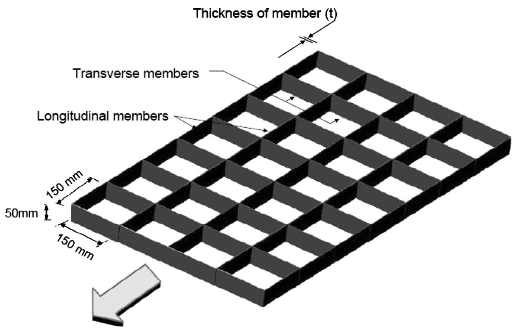


Figure 1. Typical biaxial cellular reinforcement.

is available in literature demonstrating the pullout analysis of 3D reinforcement.

The present paper, concentrates mainly on bearing type of mechanism of cellular reinforcement. pullout analysis for cellular reinforcement is performed and results are visualized with finite element software, Plaxsis-V8, by simulating the pullout test of cellular reinforcement.

2 CELLULAR REINFORCEMENT

Cellular reinforcement is a type of reinforcement in which in addition to the length and breadth as like of the conventional two dimensional 2D reinforcement; the third dimension in the form of depth of reinforcement is added. Materials like steel or geosynthetics may be used to manufacture cellular reinforcements. Such reinforcement is proposed as an alternative to conventional horizontally placed 2D reinforcement in soil reinforcement techniques like reinforced soil walls.

Figure 1 shows the longitudinal and transverse reinforcing elements, connected at right angle to each other forming a three dimensional, honeycombed, cellular like structure, called as ‘cellular reinforcement’. The beneficial effects of the reinforcement pullout are derived from the passive resistance provided by transverse elements, along with the frictional resistance of cellular structure. A better reinforcing element thus formed is expected to perform well in tension behavior as well as pull-out behavior, than the conventional two dimensional reinforcements.

3 PULLOUT RESISTANCE OF CELLULAR REINFORCEMENT

Figure 2 shows points of tangency for grid and cellular reinforcement. In case of grid reinforcement as shown in Figure 2(a); if height of reinforcement (H) is increased, for a constant spacing (S) then point of tangency appears closer and the reinforcement practically would become a sheet as shown in Figure 2(b), decreasing the bearing resistance to a negligible value. But, in case of cellular reinforcement as shown in Figure 2(c), if height of reinforcement (H) is increased, for a constant spacing (S) then point of tangency does not seem to be closer and the reinforcement practically would not be seen as sheet, as shown in Figure 2(d), increasing the bearing resistance. However, in this case, the bearing resistance may influence due to interference of bearing members in bearing mechanism.

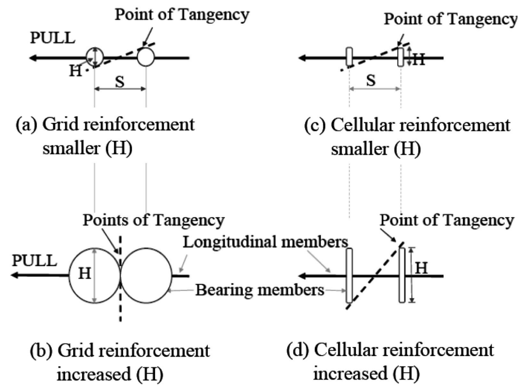


Figure 2. Points of tangency for grid and cellular reinforcement.

3.1 *Pullout analysis of cellular reinforcement*

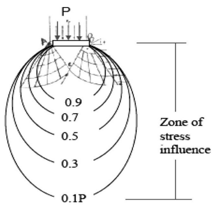
The analysis of cellular reinforcement assumes the bearing members of reinforcement as a strip footing in deep soil. Pullout analysis of cellular reinforcement can be performed on some what similar lines as like bond for geogrid.

In case of cellular reinforcement, assuming the bearing member as a strip footing (Fig. 3a, b), the zone of influence is assumed as 3 times the height of bearing members. Therefore, the interference between bearing members in bearing resistance development can be taken in account after the S/H ratio decrease below 3.

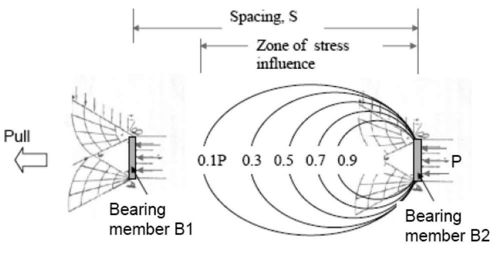
In analysis of bond for cellular reinforcement (i) It is assumed that the two components of bond i.e., frictional resistance and bearing resistance are independent and can be calculated separately and added, (ii) Frictional resistance can be calculated from the top and the bottom part reinforcement area which is solid, and can be obtained from pullout test conditions as,

$$(Pp)_f = 2\,\alpha_S\, L_r\, \sigma'_n \tan\delta \tag{1}$$

and (iii) Bearing resistance can be calculated as given by Jewell et al. (1985).



(a) Conventional footing



(b) Cellular reinforcement (plan view).

Figure 3. Zone of interference between bearing members.

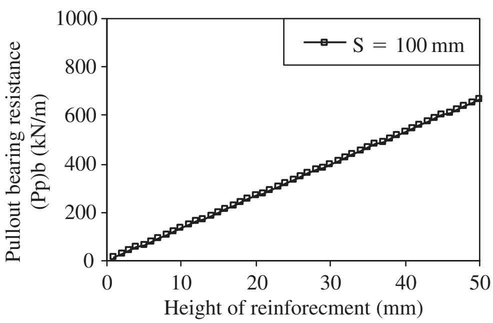


Figure 4. Relation between bearing resistance and height of reinforcement.

$$(Pp)_b = \left(\frac{L_r}{S}\right) \alpha_b \, H \, \sigma'_b \tag{2}$$

Here, σ'_b can be calculated using general shear failure mechanism,

$$\frac{\sigma'_b}{\sigma'_n} = e^{(\pi \tan \phi')} \tan^2 \left(45 + \frac{\phi'}{2}\right) \tag{3}$$

where, $(Pp)_f$ is the frictional contribution in pullout of reinforcement; α_s = fraction of reinforcement plan area which is solid; L_r = reinforcement length; σ'_n = normal stress; δ = skin friction angle between soil and reinforcement; $(Pp)_b$ is the bearing contribution in pullout of reinforcement, S = spacing between bearing members; α_b = fraction of total area available for bearing; H = height of reinforcement; σ'_b = bearing stress and Φ = angle of soil friction. For a particular set of data with a unit width of reinforcement ($\alpha_b = 1$, $\sigma'_n = 100$ kN/m, Lr/S = 4 and S = 100 mm), the relation between pullout bearing resistance $(Pp)_b$ and reinforcement height (H) is determined with the help of computer program with Matlab-7, and plotted as shown Figure 4. Here, as H is increasing, $(Pp)_b$ is also increasing.

Table 1. Data set taken for FEM analysis.

Reinforcement	Spacing (S)	100 mm
	Height (H)	3 mm to 50 mm
	Length (Lr)	400 mm
Plate element	EA	8400 kN/m
	Depth (d)	2.1 mm
Soil	C	10 kPa
	Φ	35°
	γ	18 kN/m^3
Interface	R	0.100
Normal load	σ_n	100 kN/m
Pullout load	Pp	1 to 100 kN/m

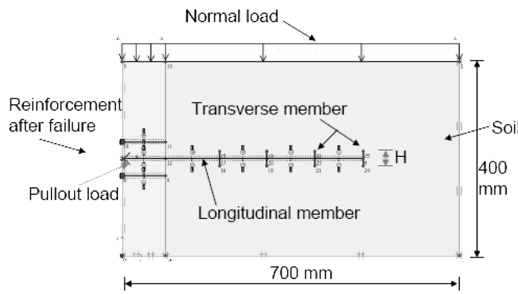


Figure 5. Geometry showing FEM simulation of pullout test of cellular reinforcement.

3.2 *Finite element analysis of cellular reinforcement*

The assumptions made in the theoretical analysis are checked by visualizing outputs from finite element method (FEM) with software, Plaxsis-V8. A numerical set of data considering a unit width of reinforcement, as shown in Table 1 is assumed for finite simulation purpose. Figure 5 shows the geometry of Pullout test simulation.

4 RESULTS AND DISCUSSION

4.1 *Load verses displacement for cellular reinforcement*

Pullout failure is simulated in FEM by increasing pullout load and the displacement is observed for different

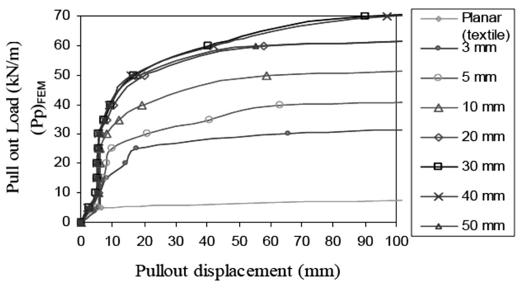


Figure 6. Relationship between pullout load and displacement for cellular reinforcement.

Table 2. Pullout load for various height of cellular reinforcement at a displacement of 20 mm.

Height of cellular reinforcement (mm)	Pullout load (kN/m)
3	25.5
5	29.5
10	40.0
20	49.5
30	52.5
40	52.5
50	49.0

heights of reinforcement. Figure 6 shows pullout load and displacement curve for various heights of cellular reinforcement (3 mm–50 mm, including 2D planar textile); for a spacing of 100 mm and normal load equal to 100 kN/m. Here, for a displacement of 20 mm, pullout load is observed increasing with increasing in height of cellular reinforcement up to a height of 40 mm but for 50 mm height of cellular reinforcement pullout load is observed decreased, as shown in Table 2. However, the rate of increase in pullout resistance is observed decreasing after the pullout displacement of 20 mm.

The bearing resistance obtained from FEM analysis for pullout test is compared with the bearing resistance obtained in Figure 4. It is found that in case of FEM analysis, the rate of increase in pullout resistance is reduced than that of Figure 4. Hence a reduction factor k is empirically adopted. Reduction factor k can be defined as,

$$k = \left(\frac{(Pp)_b}{(Pp)_{FEM}} \right) \quad (4)$$

where, pullout bearing resistance, $(Pp)_b$ can be obtained from Eq^n 2 and pullout bearing resistance from FEM analysis, $(Pp)_{FEM}$ can be obtained from Plaxis V-8 simulation. For each height of cellular reinforcement reduction factor k is obtained for a normal load of 100 kN/m and is plotted as shown in Figure 7. The reduction factor is observed decreasing with increase in height of cellular reinforcement.

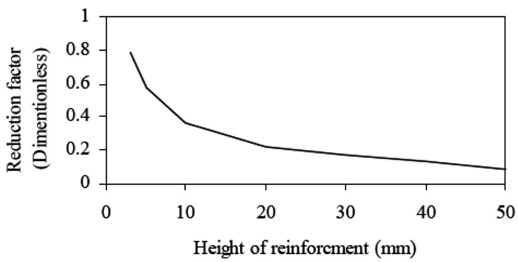


Figure 7. Relation between reduction factor and height of cellular reinforcement, for normal load of 100 kN/m.

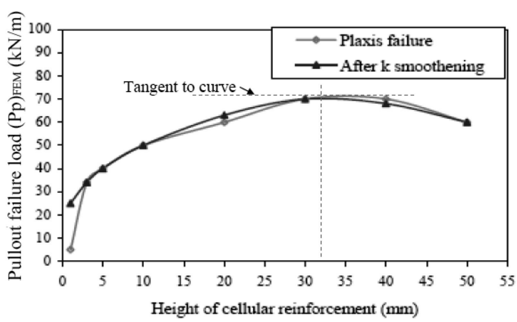


Figure 8. Relationship between pullout failure load and height of cellular reinforcement.

4.2 *Pullout failure load verses height of cellular reinforcement.*

Figure 8 shows relationship between pullout failure load and height of cellular reinforcement. Ultimate pullout resistance is observed increasing with increase in height of cellular reinforcement up to a height of 32 mm i.e., (S/H) ratio of 3.1 (approximately). Further increase in reinforcement height corresponds to decrease in pullout resistance. This shows that there is interference between bearing members after (S/H) ratio decreases below 3.1 (approximately) which supports the assumptions made in analysis.

4.3 *Pullout displacement verses height of cellular reinforcement.*

Figure 9 shows the relation between pullout displacement and height of cellular reinforcement, taken from Figure 6; measured at a particular pullout load of 50 kN/m. It is observed that the pullout displacement is reducing with increase in height of cellular reinforcement. It is observed that the pullout displacement for 30 mm height of cellular reinforcement is equal to

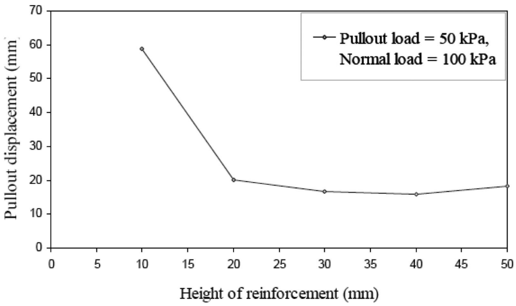


Figure 9. Relationship between pullout displacement and height of cellular reinforcement for the pullout load of 50 kN/m.

Table 3. Displacement at pullout load of 50 kN/m for various height of cellular reinforcement.

Height of cellular reinforcement (mm)	Displacement (mm)
10	58.91
20	20.24
30	16.62
40	16.04
50	18.2

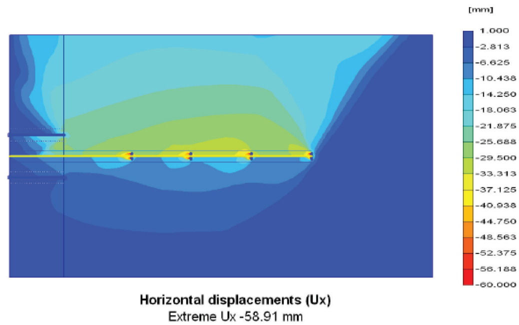
16.62 mm as shown in Table 3. The reduction in displacement is negligible after 30 mm height of cellular reinforcement i.e., below the (S/H) ratio of 3, which increases for a reinforcement height of 50 mm.

4.4 *FEM visualization of horizontal displacement for different heights of cellular reinforcement*

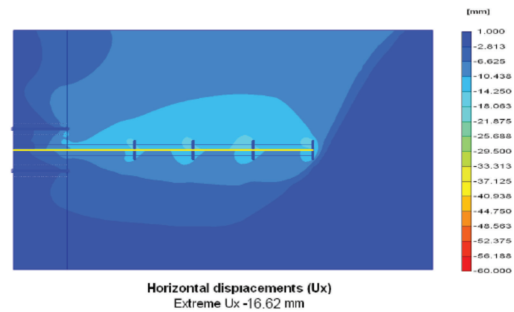
Figure 10 shows FEM visualization of horizontal displacement, from Plaxis V-8, for different heights of cellular reinforcement with the pullout load of 50 kN/m. It is observed that in case of 10 mm height of cellular reinforcement, the extreme horizontal displacement, in front of bearing member is 58.91 mm, as shown in Figure 10(a). While, in case of 30 mm height of cellular reinforcement, the extreme horizontal displacement, in front of bearing member is observed reduced to a value of 16.62 mm, as shown in Figure 10(b). This shows that there is significant amount of reduction in horizontal displacement with increase in height of cellular reinforcement.

4.5 *FEM visualization of horizontal stresses for different heights of cellular reinforcement*

Figure 11 shows FEM visualization of horizontal stresses, from Plaxis V-8, for different heights of cellular reinforcement with the pullout load of 50 kN/m.



(a) Height of cellular reinforcement = 10 mm



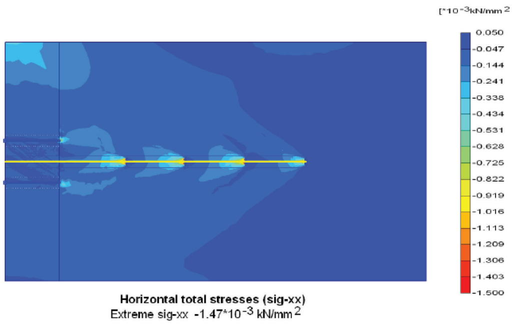
(b) Height of reinforcement = 30 mm

Figure 10. FEM visualization of horizontal displacement for different heights of cellular reinforcement.

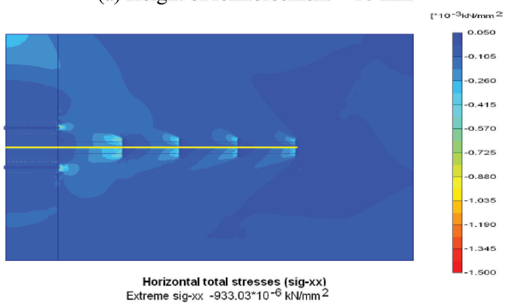
It is observed that for 10 mm height of cellular reinforcement, the extreme horizontal stress is 1.47×10^{-3} kN/mm^2, as shown in Figure 11(a) and for 30 mm height of cellular reinforcement, extreme horizontal stress is 0.933×10^{-3} kN/mm^2, as shown in Figure 11(b), which shows that there is reduction in horizontal stress with increase in cellular reinforcement height.

5 CONCLUSION

Cellular type geometry of reinforcement is found to be better performance in pullout analysis than that of 2D type reinforcement. Pullout capacity is observed increasing with increase in height of cellular reinforcement up to spacing to height ratio (S/H) of 3.1. If the (S/H) ratio is less than 3.1, the pullout capacity is decreasing with increase in height of cellular reinforcement. Pullout displacement is found decreasing significantly with increase in height of cellular reinforcement, up to 30 mm height of reinforcement, after which the decrease in displacement is negligible. Finite element results for pullout load and horizontal displacement are found supportive to the assumptions



(a) Height of reinforcement = 10 mm



(b) Height of reinforcement = 30 mm

Figure 11. FEM visualization of horizontal stresses for different heights of cellular reinforcement.

made in the theoretical analysis of cellular reinforcement. Also, it is visualized in Plaxis V-8, that there is significant reduction of horizontal stress with increase height of cellular reinforcement.

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